Selected problems of contact measurements of surface texture

Wybrane zagadnienia stykowych pomiarów struktury geometrycznej powierzchni

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The article presents an analysis of selected factors affecting obtained values of roughness parameters of surface texture. The study was conducted by applying a material standard of PSS (periodic sinusoidal shape) type and for measurements carried out with the use of stylus instrument.

KEYWORDS: surface texture, credibility of measurement, material measures

Modern technology related to the production of machines and mechanical elements allow the formation of predetermined shape and quality of the surface finish [1]. The state of the surface texture is one of the most important determinants of such properties as: sliding and lubricating properties, abrasion resistance, fatigue strength, thermal conductivity, corrosion resistance and tightness of joints. It seems that identifying the sources of errors affecting the uncertainty of measurement with the contact profilometers, is crucial [2-4].

Considerations refer to the surface of a periodic nature. In order to ensure the reliability of contact measurements of the surface roughness at an amplitude of several tens of nanometers and the unequal spacing of several micrometers, it is necessary to analyze the influence of particular measurement parameters and factors that have a decisive influence on its result. The most important of these factors can be divided into the following groups [5]:

- external disturbances: temperature gradient [6] and vibration;
- measuring equipment: tip size, density of the horizontal sampling, vertical resolution of the transmitter, noise of the device, moving speed of the stylus, measuring pressure,
- measured object: clean surface, plastic deformation of the material;
- software: accuracy calculation procedures of roughness parameters.

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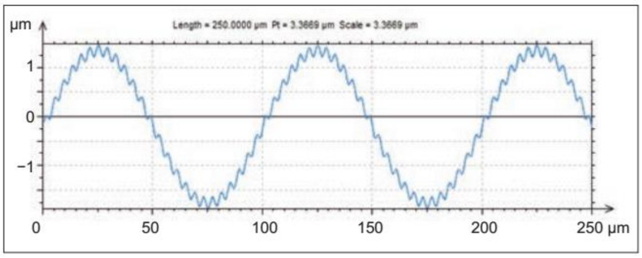

Fig. 1. PSS standard profile

To verify how selected factors affect the results of periodic surface measurements, PSS (periodic sinusoidal shape) standard [7] with nominal parameters *RSm* = 100µm, *Pt* = 3µm, *Ra* = 1µm in the form of two superimposed sinusoidal profiles with a wavelength λ_1 = 100µm and λ_2 = 4µm (fig. 1), was used.

Repeatability of measurements

In order to determine the precision of the standard measurements under repeatability conditions, a series of 50 measurements were carried out at the same location and under the following conditions:

- tip size: α = 60°, r_{tip} = 2 µm;
- force of the imaging blade: *F* <1 mN;
- measuring speed: *v* = 0.1 mm/s;
- sampling density along the *X* axis: Δx = 0.125 mm.

The coefficient of variation was used as a measure of the precision of the measurement under repetition conditions. Fig. 2 shows values of coefficients of variation for individual parameters. The results of subsequent measurements of the *Rp* parameter are shown in fig. 3. The apparent tendency of lower values of the parameter is most likely related to the plastic deformations of the wavelengths of λ_2 = 4µm. A similar trend occurs with the R_z, R_c and R_t parameters. This is supported by the results of the span of these parameters on the level of 60 nm presented in Table I. Parameter R_v values show definitely another trend for subsequent measurements and the span value of 18 nm.

The measurements show that the highest dispersion characteristics are indicated by results of height parameters concerning the maximum features of ridges and hollows: *Rp, Rv, Rz, Rc, Rt*. Significantly lower dissipation characterizes the amplitude parameters of the mean elevations of *Ra* and *Rq* profile, while the smallest is the horizontal distance parameter *RSm*.

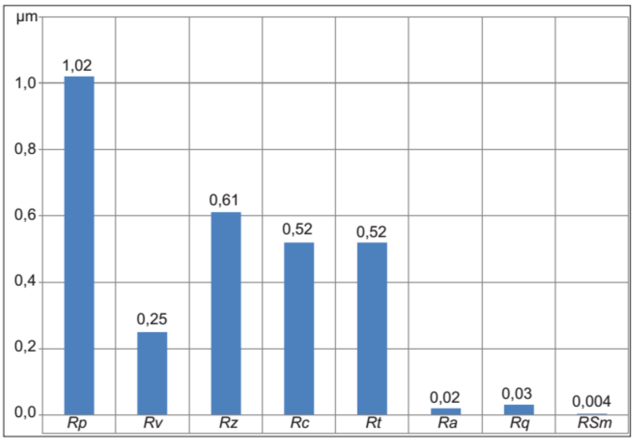

Fig. 2. Values of variability coefficients for individual roughness parameters

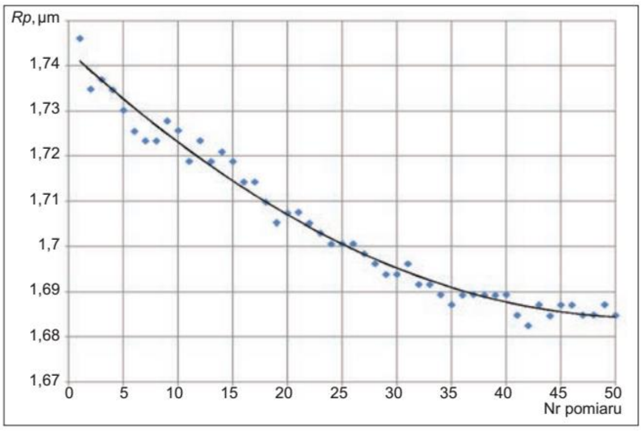

Fig. 3. *Rp* values for subsequent measurements

TABLE I. Spread of results obtained for individual parameters

Spread							
Rp, nm	*Rv*, nm	*Rz*, nm	*Rc*, nm	*Rt*, nm	*Ra*, nm	*Rq*, nm	*RSm*, µm
64	18	77	65	63	1	1	0,01

Influence of geometry of the diamond tip

The stylus tip of the contact profilometer is an element that directly contacts with the measured surface and its geometry (cone angle and rounding radius) and the technical condition (possible damage) depends on the traced profile, which, together with the reference profile, is the basis for determining the total profile. Total profile after elimination of the nominal curvature and a filter λ_s resulting in an original profile, which is the basis to determine the profile parameters.

In measurements performed to verify the effect of the roughness parameters obtained on the geometry of the

stylus tip, three mapping tips with the following nominal geometry were used:

- tip No. 1: α = 60°, r_{tip} = 1 µm;
- tip No. 2: α = 60°, r_{tip} = 2 µm;
- tip No. 3: α = 90°, r_{tip} = 2 µm.

The state of the tip has been tested on a scanning electron microscope. The SEM image of tip No. 2 is shown in fig. 4. The radius measurements of the tip were performed on a PRB (razor blade) pattern. The result of the shape measurement of tip No. 2 with determined radius is shown in fig. 5. All tips used for the measurements have radii less than the nominal values.

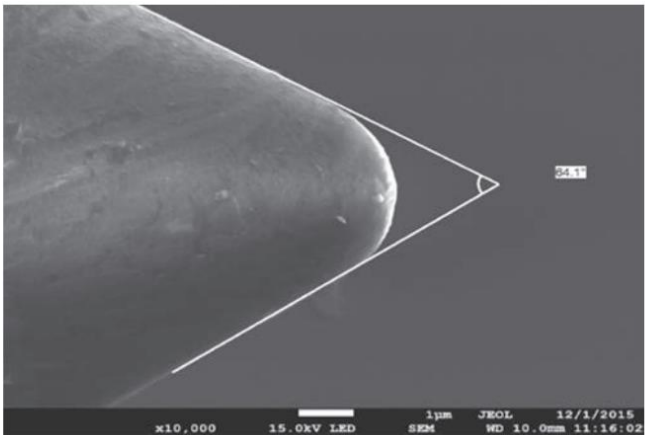

Fig. 4. SEM image of tip No. 2

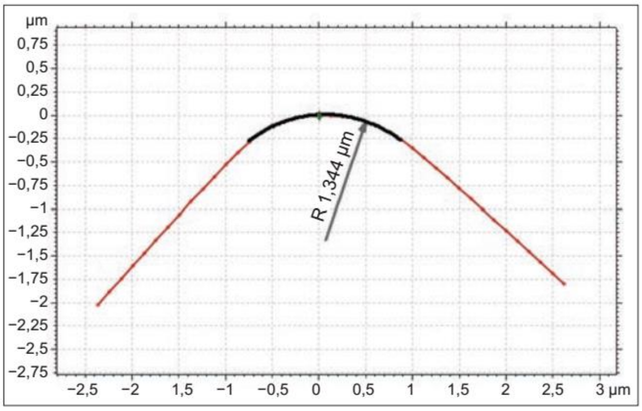

Fig. 5. Determination of radius of tip No. 2

Parameters at which the standard measurements were made, were as follows:

- tip force: *F* <1 mN,
- measuring speed: *v* = 0.1 mm/s,
- sampling density along the *X* axis: Δ*x* = 0.125 mm.

Each tip was subjected to a series of 10 measurements. The obtained average values of roughness parameters for individual tips shown in fig. 6 and in Table II.

Taking into account the geometry of the profile with a wavelength λ_2 = 4µm (the radius of the profile determined by the atomic force microscope *r* = 4.92µm), the tips used for the measurements should not be mechanical filters due to their geometry (r_{tip} = 1 µm and 2µm). The spread of results for individual tips should be treated as a lack of precision in conditions. In addition to the geometry of the tip on the modified measurement conditions, a roughness distribution is calculated according to the measurement location on the standard.

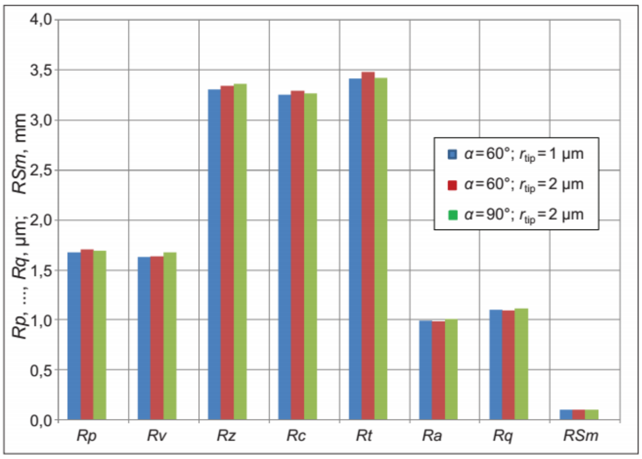

Fig. 6. Roughness parameter values

TABLE II. Roughness values obtained for individual tips

	α = 60° r_{tip} = 1 µm	α = 60° r_{tip} = 2 µm	α = 90° r_{tip} = 2 µm	Mean value	Variability coefficient, %
Rp, µm	1,679	1,704	1,688	1,690	0,7
Rv, µm	1,628	1,636	1,678	1,647	1,6
Rz, µm	3,307	3,340	3,365	3,338	0,9
Rc, µm	3,256	3,294	3,269	3,273	0,6
Rt, µm	3,413	3,477	3,425	3,439	1,0
Ra, µm	0,991	0,986	1,004	0,994	0,9
Rq, µm	1,101	1,095	1,113	1,103	0,8
RSm, mm	0,10151	0,10150	0,10160	0,10154	0,05

Influence of the measuring speed

Measurements to determine the effect on the obtained roughness and shape of the mapped profile of the speed of movement of the tip has a mapping was performed using the following settings:

- tip No. 2: α = 60°; R_{TIP} = 2µm;
- tip force: F < 1 mN;
- sampling density along the X axis: Δx = 0.125µm;
- measuring speed: v = 0.1 mm/s, v = 0.25 mm/s, v = 0.5 mm/s, v = 1 mm/s, v = 2 mm/s.

For each speed value, a series of 10 measurements was performed. The obtained values of mean roughness parameters are presented in fig. t and in Tab. III, while the speed and the impact on the shape of the mapped profile - in fig. 8.

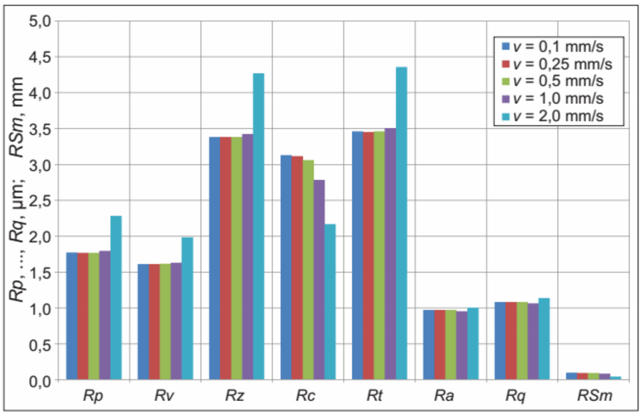

Fig. 7. Roughness parameter values depending on the measuring speed

TABLE III. Roughness parameter values obtained for the individual measuring speed

Mapping blade feedrate v, mm/s	0,1	0,25	0,5	1,0	2,0
Rp, µm	1,773	1,770	1,767	1,797	2,284
Rv, µm	1,613	1,614	1,615	1,630	1,983
Rz, µm	3,386	3,383	3,383	3,426	4,267
Rc, µm	3,130	3,119	3,064	2,784	2,168
Rt, µm	3,464	3,452	3,464	3,507	4,358
Ra, µm	0,972	0,971	0,970	0,954	1,002
Rq, µm	1,084	1,083	1,082	1,065	1,135
RSm, mm	0,094	0,094	0,091	0,080	0,038

The measurements show that the change in measuring speed from v = 0.1 mm/s to v = 1 mm/s has little effect on the roughness values obtained and the shape change of the wavelength λ_2 = 4 µm. Results for measuring speed v = 2 mm/s are characterized by a significant increase in *Rp, Rv, Rz* and *Rt* values - respectively: 28.6%, 22.6%, 25.7% and 25.5% mean values calculated for the velocity of v = 0.1 mm/s to v = 1 mm/s - and a distinct decrease in the value of the parameter *RSm* - by 57.3%. There was also a moderate increase in *Ra* and *Rq* parameters - by 3.7% and 5.3%, respectively. The increase of the amplitude parameters for velocity v = 2 mm/s is related to the occurrence of the *flight* phenomenon of the tip, as evidenced by the character of the profile (fig. 8) [8].

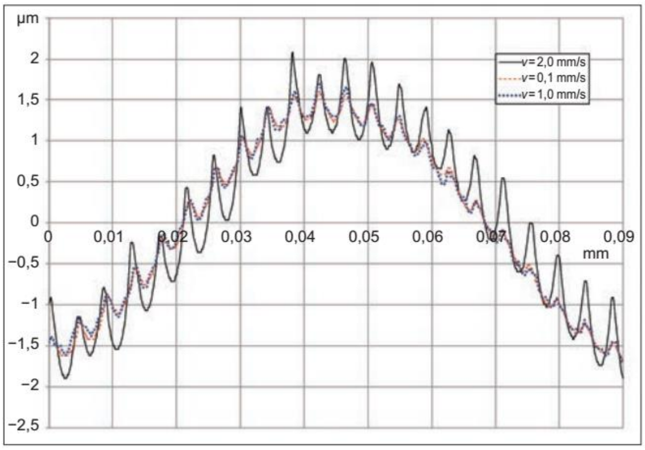

Fig. 8. Changing the profile form depending on the measuring speed

Influence of the pressure force of the tip

In order to determine the effect of increased measuring pressure, the gauge was measured with a profilometer whose measurement pressure was several times higher than the nominal value. As a result of the increased tip force on the pattern there is a plastic deformation of the material causing damage to its surface.

The effect of increased unitary pressures on the surface of the pattern is shown in its isometric image, made on the atomic force microscope (fig. 9). Excessive unit pressures exerted by the measuring tip caused complete destruction of inequalities of wavelength λ_2 = 4 µm and amplitude A_2 = 0.15 µm. Performing measurements under such conditions results in a false image of surface stereometry and erroneous values of roughness parameters. Fig. 10 compared two separate profiles: one of the surface pattern without plastic deformation, and another - in the area where the surface damage has occurred.

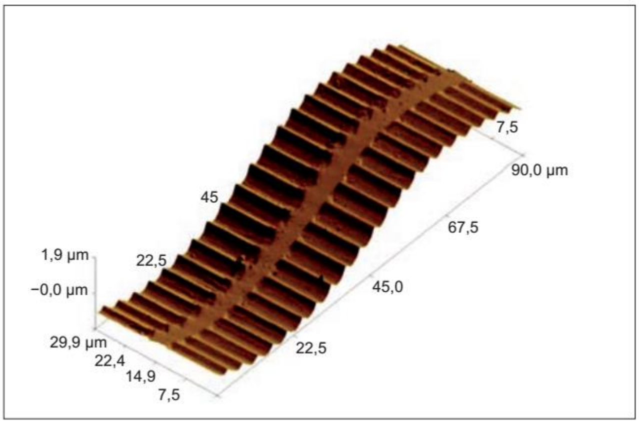

Fig. 9. Isometric image of damaged surface of standard

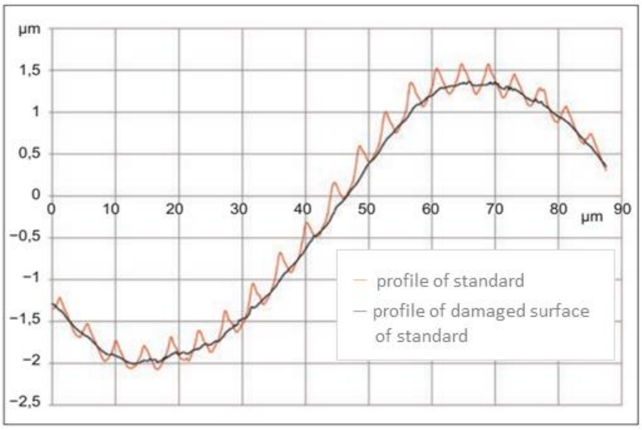

Fig. 10. Standard profiles without and with plastic deformations

The problem of permanent deformation of the surface caused by the tip of the contact profilometer is especially related to the measurement of elements of lower hardness materials. In this case, the only solution is to use non-contact method of measuring surface texture.

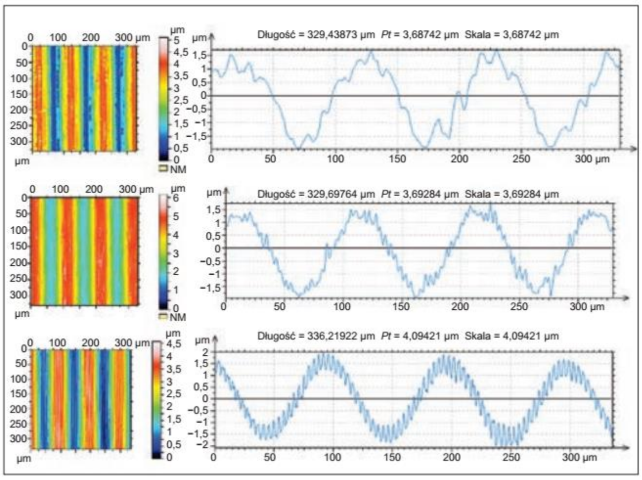

Fig. 11. The results of the measurement of standard using an optical instrument with × 10, × 20 and × 50 lenses

Optical measurements involve a number of problems relating to: dependence of horizontal sampling on the lens used, occurrence of unmeasured points in the case of sloping highs or light scattering through the material of the measured element.

The influence of applied lens and horizontal resolution on the geometrical accuracy of the pattern using an optical instrument is shown in fig. 11. Measurements were made using an optical device using the coherent correlation interferometry method, equipped with lenses of magnitude ×10, ×20 and ×50. These lenses provide horizontal resolution respectively 1.65µm × 1.65µm; 0.88µm × 0.88µm and 0.33µm × 0.33µm. Full surface reproduction of the standard was achieved with a ×50 lens.

Conclusions

Measurements of precision under repeatability conditions have shown that *Rp* results are characterized by the largest scatter. There was a tendency that for subsequent measurements less values of this parameter and associated parameters *Rz, Rc* and *Rt* were obtained, which may be due to plastic deformations of the profile at several tens of nanometers.

Significant changes in amplitude parameters have been noted in the case of a measuring speed increase of more than 1 mm/s. This change is due to the loss of contact between the tip and the measured surface of the standard.

For surfaces containing components with an amplitude of several hundred nanometers, it is important that the tip pressure does not exceed the permissible values, because otherwise the plastic deformation of the sample material will occur resulting in the situation that the roughness values will be unreliable.

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