MEASUREMENT PRINCIPLES OF 3D ROUGHNESS PARAMETERS

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Abstract. In this scientific article recommendations for a three-dimensional surface roughness parameter determination of machine elements are developed. As the base of this work the number of surface roughness uncorrelated points, which are defined on the basis of autocorrelation function characteristics, was chosen. The correlation interval and the number of uncorrelated points for roughness sampling length as well as for the roughness average step were calculated. The research was carried out for irregular roughness surfaces, which have been treated by flat grinding, shot peening and electroerosion. As a result, the recommended minimal number of measurement points for reliable 3D roughness parameter determination along the evaluation length was obtained and it draws up 300 points.

Keywords: surface texture, 3D roughness, autocorrelation function, number of measurement points.

Introduction

Nowadays, the surface roughness plays a very large role in the mechanical engineering sphere, as it directly affects the quality and applicability of parts. Surface treatment has influence on industrial application of the parts, for example, provision of wear-resistance, adhesion, anti- slip properties, lubricant retention etc. It is important to accurately determine 3D surface roughness parameters, but today there is no effective methodology for parameter determination [1; 3].

Experience shows that the most important aspect on precise surface roughness measurement determination is selection of the measurement point in XY plane. From one side of view increase of the measurement points improves the measurement quality, but from the other side, such step significantly increases the measurement time. Because of this problemin this paper the authorsdid determination for the minimal necessary number of measurement points that gives reliable enough measurement, jet allowing to do measurements with the least expenditure of time using the correlation function properties [2].

Materials and methods

The given question is necessary due to the 3D surface roughness experiment organization. The greater the number of points used in the experiment, the more time is needed to carry out this experiment. Using Taylor Hobson Talysurf Intra 50 measuring equipment for 400 measuring points in both the X and Y directions more than 3 hours are consumed. Therefore, it is important to determine the minimum number of points, which provides the necessary accuracy of main surface roughness parameters.

For measurement time reduction without losing measurement precision the authors recommend to use the number of surface roughness uncorrelated points, which usually tends to be significantly less than the freely selected number of points. To determine the number of uncorrelated points 3D roughness the autocorrelation function should be known. Such function example for the surface with irregular roughness is given in Figure 1.

If the surface profile is used instead of 3D surface the autocorrelation function will look as shown in Fig. 2.

Figures 1 and 2 show that the autocorrelation function has a descending character. For the further analysis we will use a simple correlation function approximation:

$$\rho(\tau) = \frac{1}{1 + \alpha \cdot \tau^2}, \tag{1}$$

where τ – interval between the surface’s profile points;
α – approximation parameters of the autocorrelation function.

Such function is widely used in case of irregular roughness analysis. For this autocorrelation function correlation interval is calculated by the following equation [4]:

$$\tau_k = \int_0^\infty |\rho(\tau)| d\tau \,, \tag{2}$$

After inserting the autocorrelation function expression according to equation (1) into equation (2) and doing the integration, the following equation is obtained:

$$\tau_k = \frac{\pi}{2\sqrt{\alpha}} \,. \tag{3}$$

The coefficient α can be determined from the number of profile zeros $n(0)$ per unit length by the following equation [6]:

$$E\{n(0)\} = \frac{1}{\pi}\left(-\rho^{(2)}(0)\right)^{\frac{1}{2}} , \tag{4}$$

where $\rho^{(2)}(0)$ – second derivative of the autocorrelation function to $\tau = 0$;
$E\{n(0)\}$ – mathematical expected value of the number of profile zeros per unit length.

Then equation (3) can be transformed as follows:

$$\tau_k = \frac{\sqrt{2}}{2} \cdot \frac{1}{E\{n(0)\}} , \tag{5}$$

The equation (5) shows that for determination of the correlation interval the number of profile zeros $n(0)$ per unit lengthneeds to be known.

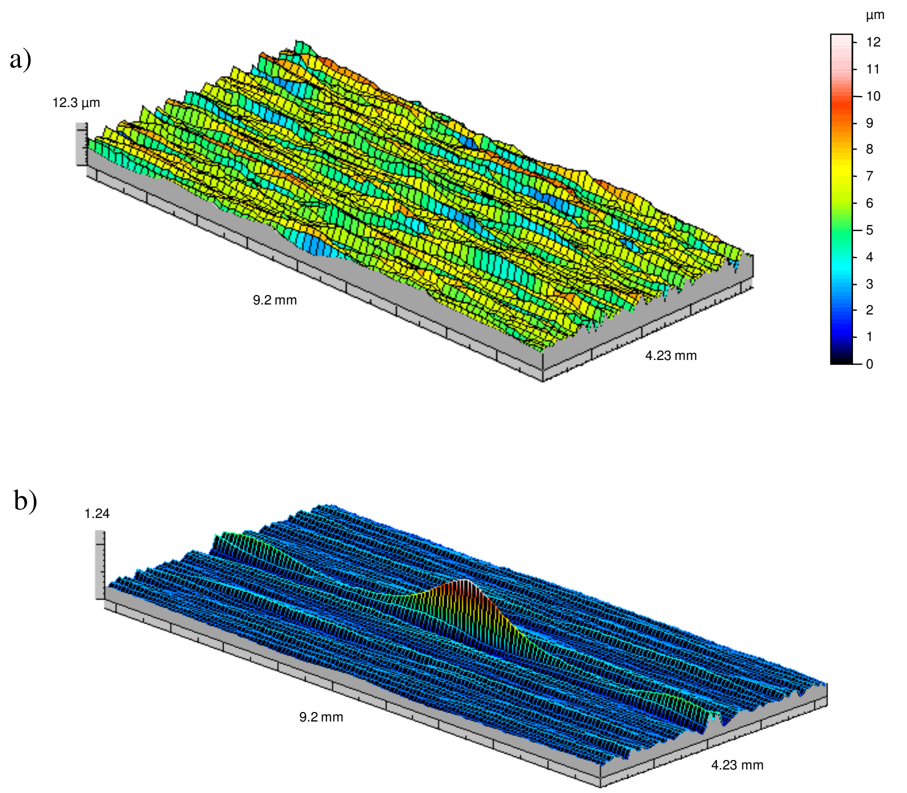

Fig. 1. **Flat grinded surface:** a – 3D roughness; b – autocorrelation function

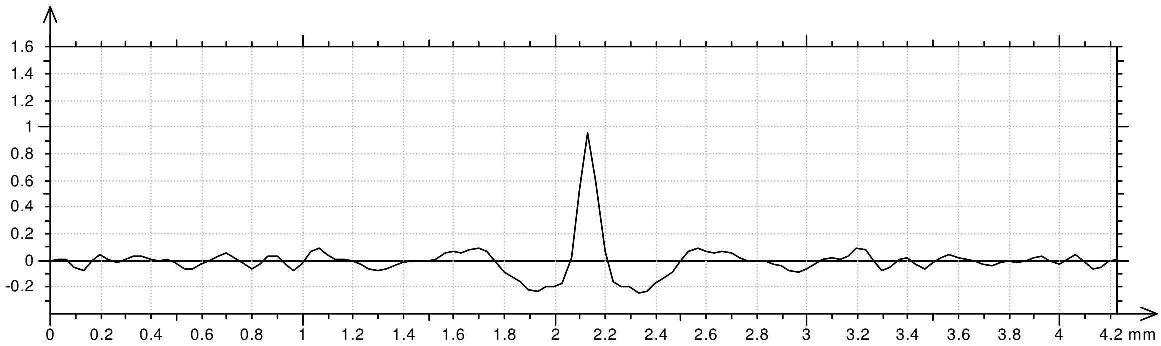

Fig. 2. **Autocorrelation function of surface profile**

Results and discussion

To determine the number of profile zeros $n(0)$ the research of surfaces with irregular character was used. Measurement data were obtained by processing the five sampling lengths according to the standard ISO 4288 requirements. The results are given in Table 1, where *Ra* – arithmetic average of absolute values, *l* – sampling length.

Table 1

Average values of profile roughness parameters

Type of treatment	*Ra*, µm	*n*(0), mm^{-1}	*l*, mm
Flat grinding	2.51	15	2.5
	1.37	27	0.8
	0.89	34	0.8
	0.56	51	0.8
Shot peening	1.25	12	0.8
Electroerosion	1.28	12	0.8

To calculate the number of uncorrelated points along the roughness step, the following equation is used [4]:

$$E\{RSm\} \approx \frac{2}{E\{n(0)\}}, \tag{6}$$

where *RSm* – average step of roughness, mm;

The number of uncorrelated points along the roughness step for the given correlation function is determined as:

$$PS_{RSm} = \frac{E\{RSm\}}{\tau_k} = \frac{4}{\sqrt{2}} = 2{,}8 \approx 3, \tag{7}$$

where PS_{RSm} – number of uncorrelated points along the roughness step.

The equation (7) shows that the average roughness step includes approximately 3 points, which are not mutually correlated. Let us analyze the influence of such points on a real roughness profile (see. Fig. 3, a), where $RSm_l$is a roughness step in a crosswise processing direction. It can be seen that with the following number of points the roughness in one step length looks strongly simplified. Somewhat better situation is given by the increased number of points PS_{RSm} = 5 (see. Fig. 3, b).

To select the optimal number of points, on which the roughness parameter accuracy and the consumption of the experiment organizing time depend, the data from the literature source [5] as shown in Table 2 were used, where PS_l – number of uncorrelated points along the sampling length.

According to the data shown in Table2 it can be seen that at various numbers of points along the sampling length the parameter Ra values are slightly different. To select the minimally necessary number of points, it is assumed that the detection error for the parameter Ra should be less than 10 %. During the course of the calculation it was found that measurement error for the parameter Ra value at

100 points along the sampling length is 8-9 % (seeTable 3); It can be considered as the minimal necessary number of measurement points along the sampling length in one direction, what is required for 3D surface roughness parameter determination, proceeding from the measurement time and precision of the parameter *Ra*.

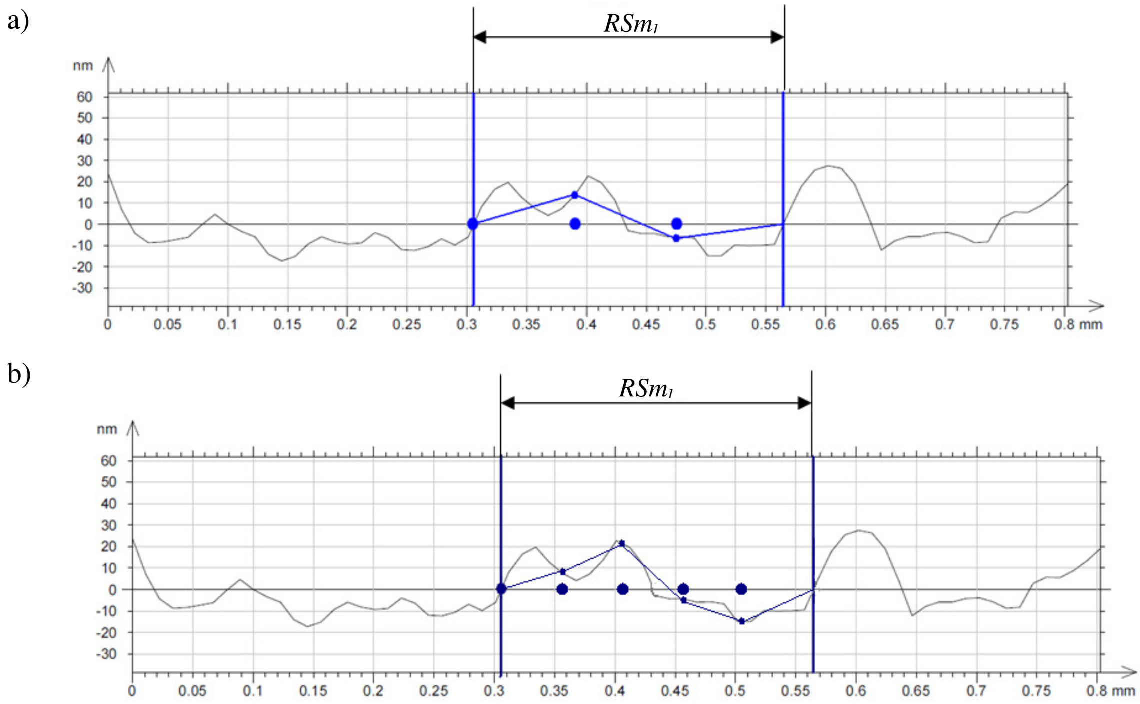

Fig. 3. **Representation of flat grinded surface profile in accordance with the number of uncorrelated points along the roughness step *RSm*:** a – 3 points; b – 5 points

Table 2

Measurement results of parameter *Ra*

No.	PS_l	Flat grinding	Shot peening	Electroerosion
		Ra, µm		
1	50	1.04	1.24	1.16
2	100	1.31	1.41	1.35
3	150	1.38	1.49	1.44
4	200	1.40	1.52	1.47
5	250	1.41	1.52	1.47
6	300	1.45	1.54	1.49

Table 3

Measurement error of parameter *Ra*

No.	Type of treatment	Measuring error of parameter *Ra* to PS_l =100 points, %
1	Flat grinding	9 %
2	Shot peening	8 %
3	Electroerosin	9 %

Knowing the required number of points along the sampling length, one can calculate the number of uncorrelated points along the roughness step. First of all, the number of steps along the sampling length has to be determined:

$$N_{RSm} = \frac{l}{RSm}, \tag{8}$$

where N_{RSm} – number of steps along the sampling length.

So the number of uncorrelated points along the roughness step will be equal to:

$$PS_{RSm\cdot} = \frac{PS_l}{N_{RSm}}. \tag{9}$$

Using the data from Table 1 and equation (9) we obtain the number of uncorrelated points (see Table 4). The data from Table 4 show that the minimum number of uncorrelated points is approximately five, what approves the proposed number of uncorrelated points. Therefore, we assume that the number of uncorrelated points in one roughness step for surfaces with irregular roughness will draws up 5 points.

To measure the surface texture parameters it is necessary to know the number of the measuring points along the evaluation length, what is calculated as follows:

$$PS_{3l} = 3 \cdot PS_l, \tag{10}$$

where PS_{3l} – number of measuring points along the evaluation length, mm.

For 3D roughness measurements it is recommended to use the evaluation length that contains at least three sampling lengths,which are determined according to the standard ISO 4288 requirements. However, during data processing (filtration)one sampling length is discarded and for the parameter determination only two sampling lengths are used.

The calculation results of the number of uncorrelated points are shown in Table 4.

Table 4

Number of uncorrelated points

***l*, mm**	***RSm*, mm**	N_{RSm}	PS_{RSm}	PS_l	PS_{3l}
2.5	0.13	19	5.3	100	300
0.8	0.074	11	9.1	100	300
0.8	0.039	21	4.8	100	300
0.25	0.011	23	4.4	100	300

So the required number of measuring points along the evaluation length is 300 points. A three-dimensional surface roughness model for flat grinded surface, what was obtained by the mentioned requirement, is shown in Fig. 4.

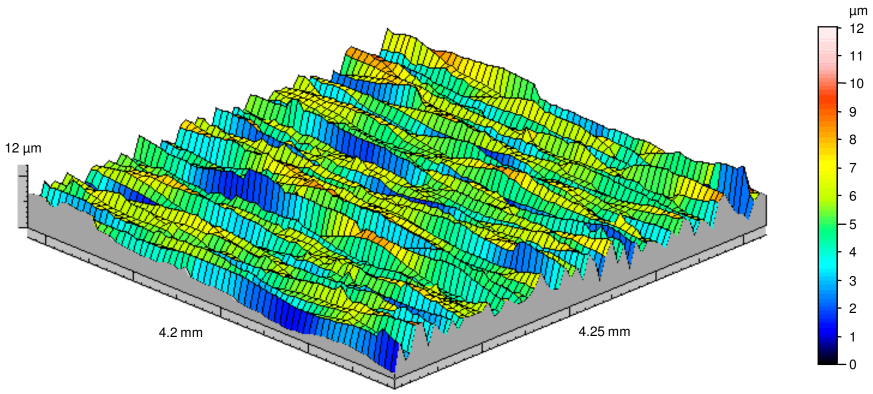

Fig. 4. **3D topography of flat grinded surface**

Conclusions

In this paper the recommendations for 3D surface roughness parameter determination were developed. The recommendations are based on the number of uncorrelated points along the roughness step. The performed calculations determine the optimal number of the measurement points for reliable enough and quick measurement data. It was found that for the surfaces with irregular roughness the number of the measuring points along the evaluation length is at least 300 points.

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