Precision assessment of surface coating roughness 3D parameters

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Abstract

Nowadays characterization of surface roughness using three-dimension (3D) methods and parameters become more and more important. This type of surface characterization provides a more complete view on the surface qualities, since the surface roughness is viewed as a spatial object. Within the last ten years intensive work is being carried out on the development of 3D roughness standards, therefore it is necessary to agree on a unified approach in the assessment of surface roughness 3D parameters. To make possible application of the ISO/DIS 25178 standard being developed one needs information on the determination of 3D surface roughness parameter precision, such as number of measurements, dimensions of measurement areas and their disposition on the measured surface. The present work provides the surface roughness assessment principles when measuring the 3D roughness of coated surfaces by means of contact-type measurement devices, based on the regularities of the theory of probability. The work considers one of the basic parameters of roughness – the surface arithmetic mean deviation *Sa,* describing surface by the help of a normal random field at a monotonously decreasing two-dimension correlation function type.

1 Precision determination Sa

The mean arithmetic deviation of surface roughness *Sa* in respect of microtoprography can be determined as

$$Sa = \frac{1}{A}\iint_{\Omega} \left| h\left(x, y \right) \right| dxdy \tag{1}$$

where *h(x,y)* – surface deviation from the mean plane;

A – area of investigation field Ω.

If $g = |h(x,y)|$, then mathematical expectation *Sa*

$$E\{\mathrm{Sa}\} = \frac{1}{A}\iint_{\Omega} dxdy \int_0^{\infty} gf(g)\,dg, \tag{2}$$

where f(g) – probability density function.

Taking into consideration the field normality and uniformity, we get

$$E\{Sa\} = \sqrt{\frac{2}{\pi}}\sigma, \tag{3}$$

where σ – standard deviation of random field *h(x,y)*.

Let's consider the parameter dispersion $D\{Sa\} = E\{Sa^2\} - E^2\{Sa\}$. Then the second centred moment *Sa* taking into consideration (1) for square field.

$$E\{Sa^2\} = \frac{1}{L^4}\int_0^L\!\!\int\!\!\iint dx_1dx_2dy_1dy_2 \int_0^{\infty}\!\!\int g_1g_2\, f(g_1,g_2)\,dg_1dg_2 \tag{4}$$

where L – side length of square section of investigation area

$$g_1 = |h_1(x_1,y_1)|;\; g_2 = |h_2(x_2,y_2)|;$$

$f(g_1,g_2)$ – density of the common distribution of values g_1 and g_2.

After solving expression (4) we obtain:

$$E\{Sa^2\} \approx \frac{\sigma^2}{2\pi\sqrt{\alpha_1\alpha_2}} + \frac{2}{\pi}\sigma^2 \tag{5}$$

where α_1; α_2 – parameters of expotential correlation function [1].

Then with the error not exceeding 2,5%

$$D\{Ra_T\} = \frac{\sigma^2}{2\sqrt{\alpha_1\alpha_2}L^2} \tag{6}$$

for isotropic roughness (when $\alpha_1 = \alpha_2 = \alpha$)

$$D\{Sa\} = \frac{\sigma^2}{2\alpha L^2} \tag{7}$$

The analysis of expression (7) shows that it is rather similar to the dispersion formula *Ra* for profile [1].

$$D\{Ra\} \approx \frac{\sigma^2}{L\sqrt{2\alpha\pi}} \tag{8}$$

However, dispersion *Sa* for the field determined in the square with side *L*, will be much smaller than dispersion *Ra* for the profile detected on the trace of *L* length.

For example, based on formula (8) we will get that

$$\frac{D\ \ Sa}{D\ \ Ra}=\sqrt{\frac{\pi}{2}}\frac{1}{\sqrt{\alpha L}} \tag{9}$$

Since for irregular roughness $\sqrt{\alpha L} > 10$, it follows from formula (9) that dispersion of parameter *Sa* is about by an order smaller of the dispersion of parameter *Ra*, determined on the length *L*, for one and the same surface. Physically it means that spread of values *Sa* will be considerably smaller than for *Ra*.

2 Experimental research

Experimental surface roughness measurements for flat grinded steel surfaces having TiN coating with *Sa* = 1,6 µm were carried out to verify the previously mentioned theoretical expressions. As it shows Fig.1 the surface roughness distribution is similar to normal.

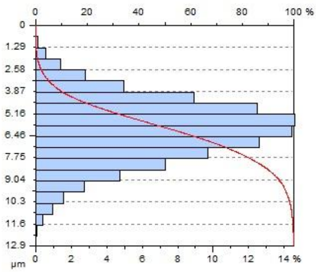

Figure 1: Surface roughness distribution of measured surface

Parameters were measured using cut-off 0.8 mm and the number of points 240 per one cut-off length. In case of *Sa* the squared measurement areas have the side lengths ($L\times L$) 2, 3 and 4 cut-off , in case of *Ra* the measurement traces *L* consisting of 2 to 8 cut-off . Were made 5 separate measurements at each above mentioned dimensions. The measurement results were processed using mathematical statistical methods [2].

Dispersion of parameter is calculated by formula:

$$\tilde{D}=\frac{\sum_{i=1}^{n}\left(X_i-m\right)^2}{n-1} \tag{10}$$

where X_i – actual value of parameter;

m – mean value of parameter of measured values;

n – number of measurements.

Root mean square:

$$\sigma_m = \sqrt{\frac{\tilde{D}}{n}} \tag{11}$$

On the supposition that probability credibility $\beta = 0.90$ and tabular value $t_\beta = 1.643$ [2] relative accuracy can be calculated:

$$\varepsilon = \tau_\beta \times \sigma_{\tilde{m}} \tag{12}$$

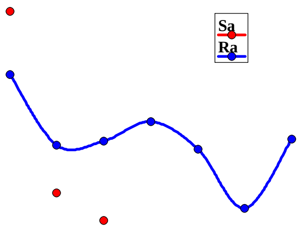

Figure 2: Relative accuracy of *Sa* and *Ra* at different *L* values

Fig. 2 shows that relative accuracy of parameter *Sa* already when the sizes of sides of square measurement area are equal to three cut-off lengths, is smaller than 4%. Besides, when increasing the length of measurement area sides we can observe further decrease of *Sa* relative accuracy. In its turn, the measurement accuracy of parameter *Ra* is variable; practically it is not influenced by the length of measurement trace.

References:

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[2] Ventcel E.S. Teorija verojatnostei (in Russian). – GI, Moscow, 1962, 563. pp.

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