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# DETERMINATION OF 3D SURFACE ROUGHNESS PARAMETERS BY CROSS-SECTION METHOD

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Currently, in the production engineering the surface roughness parameters are estimated in three dimensions, however, the equipment for these measurements is rather expensive and not always available. In many cases to buy such equipment is not economically justified. Therefore, the 3D surface roughness parameters are usually determined from the well-known 2D profile ones using the existing 2D equipment. This could be done best using the cross-section (or profile) method, especially in the case of nano-roughness estimation, with calculation of the mean values for the roughness height, spacing, and shape. This method – though mainly meant for irregular rough surfaces – can also be used for other types of rough surfaces. Particular emphasis is here given to the correlation between the surface cross-section (profile) parameters and 3D parameters as well as to the choice of the number of cross-cuttings and their orientation on the surface.

**Keywords:** *Surface roughness, cross-section method, nano-topographical surface parameters.*

## 1. INTRODUCTION

Among the methods for determination of surface roughness parameters is the cross-section method [1] consisting in determination of 3D surface roughness parameters from the well-known 2D profile ones.

In our work, the first step is choice of the input data that would ensure sufficient information for determination of the roughness height as well as of its spatial and shaping parameters. For this it is necessary to know the linear function $h(x,y)$ and matrix of the correlation momentum. The second step is to analyse the correlation between the 3D surface roughness parameters and the profile parameters using a correlation momentum matrix. We also estimate the geometrical orientation of cross-sections as well as their preferable angles and disposition.

## 2. INPUT DATA

To provide the input information (which should be minimum in size but sufficient in content) for determination of the roughness height, spacing and shape, it is necessary to know the two-argument function $h(x,y)$ [1] describing the nano-roughness as a 3D object – its first and second derivatives. We thus will denote:

$$h_1 = h(x,y)\,,\; h_2 = \frac{\partial x(x,y)}{\partial x}\,,\; h_3 = \frac{\partial h(x,y)}{\partial y}\,, \tag{1}$$

$$h_4 = \frac{\partial^2 h(x,y)}{\partial x^2}\,,\; h_5 = \frac{\partial^2 h(x,y)}{\partial x \partial y}\,,\; h_6 = \frac{\partial^2 h(x,y)}{\partial y^2}\,,$$

where $h_1$ is used for determination of roughness height parameters,

$h_2$ and $h_3$ – for estimation of surface gradient,

and $h_4$ and $h_6$ – for peak roundup.

Prior to the determination of all micro/nano-topographical parameters based on $h_1, h_2, \ldots, h_6$, values we should know their six-rank density and mutual distribution defined by the matrix:

$$\begin{vmatrix} k_{11} & k_{12} & k_{13} & k_{14} & k_{15} & k_{16} \\ & k_{22} & k_{23} & k_{24} & k_{25} & k_{26} \\ & & k_{33} & k_{34} & k_{35} & k_{36} \\ & & & k_{44} & k_{45} & k_{46} \\ & & & & k_{55} & k_{56} \\ & & & & & k_{66} \end{vmatrix} \tag{2}$$

where $k_{ij}$ are the correlation moments of $h_1, h_2, \ldots, h_6$.

We will assume that the function $h(x,y)$ can be described as a differential homogeneous random field. Then we can determine moments $k_{ij}$ using the field correlation function $K_h(\tau_1,\tau_2)$:

$$\begin{aligned} & k_{11} = K_{00} = \sigma^2,\; k_{12} = K_{10},\; k_{13} = K_{01},\; k_{14} = K_{20}, \\ & k_{15} = K_{11},\; k_{16} = K_{02},\; k_{22} = -K_{20},\; k_{23} = -K_{11},\; k_{24} = -K_{30},\; k_{25} = -K_{21}, \\ & k_{26} = -K_{12},\; k_{33} = K_{02},\; k_{34} = -K_{12},\; k_{35} = -K_{12},\; k_{36} = -K_{03}, \\ & k_{44} = K_{40},\; k_{45} = K_{31},\; k_{46} = K_{22},\; k_{55} = K_{22},\; k_{56} = K_{13},\; k_{66} = K_{04}, \end{aligned} \tag{3}$$

where $K_{ij} = \dfrac{\partial^{(i+j)} K_h(\tau_1,\tau_2)}{\partial \tau_1^i \partial \tau_2^i}, \quad \tau_1 = \tau_2 = 0$.

To observe expressions (3), matrix (2) can be rewritten as

$$\begin{vmatrix} \sigma^2 & 0 & 0 & K_{20} & K_{11} & K_{02} \\ & -K_{20} & -K_{11} & 0 & 0 & 0 \\ & & -K_{20} & 0 & 0 & 0 \\ & & & K_{40} & K_{31} & K_{22} \\ & & & & K_{22} & K_{13} \\ & & & & & K_{04} \end{vmatrix} \quad (4)$$

This matrix contains the set of the input data for describing a rough surface.

## 3. CORRELATION BETWEEN 2D AND 3D PARAMETERS OF THE SURFACE PROFILE

The formulas connecting correlation function $K_r(\varphi)$ of the section random field derivatives and the derivatives of correlation function of field $K_{i,j}$ are the following:

$$K_r(\phi) = \sum_{j=0}^{r} K_{r-j,j} C_r^j \cdot (\cos\phi)^{r-j} \cdot (\sin\phi)^j \quad (5)$$

$$C_r = \frac{r!}{j!(r-j)!}, r = 0, 2, 4...$$

From formulas (5) after mathematical transformation we obtain:

$$K_0(\phi) = K_{00} = \sigma^2 \quad (6)$$

$$K_2(\phi) = K_{20}\cos^2\phi + 2K_{11}\cos\phi \cdot \sin\phi + \\ + K_{02}\sin^2\phi \quad (7)$$

$$K_4(\phi) = K_{40}\cos^4\phi + 4K_{31}\cos^3\phi\sin\phi + \\ + 6K_{22}\cos^2\phi \cdot \sin^2\phi + 4K_{13}\cos\phi \cdot \sin^3\phi + \\ + K_{04}\sin^4\phi. \quad (8)$$

One surface cross-section allows three equations to be composed. For determination of nine values $K_{ij}$ five surface cross-sections are required [2].

After solving the set (6-8) containing nine equations, we obtain the following correlations between the 3D and cross-sectional parameters:

$$K_{00} = K_0(0^0) = \sigma^2,\ K_{20} = K_2(0^0),\ K_{04} = K_4(90^0), \\ K_{11} = K_2(45^0) - \frac{1}{2}\left[K_2(0^0) + K_2(90^0)\right], \\ K_{02} = K_2(90^0),\ K_{40} = K_4(0^0), \\ K_{22} = \frac{1}{3}\left[K_4(45^0) + K_4(135^0)\right] - \frac{1}{6}\left[K_4(0^0) + K_4(90^0)\right]. \quad (9)$$

Figure 1 shows the orientation of five cross-sections on the surface.

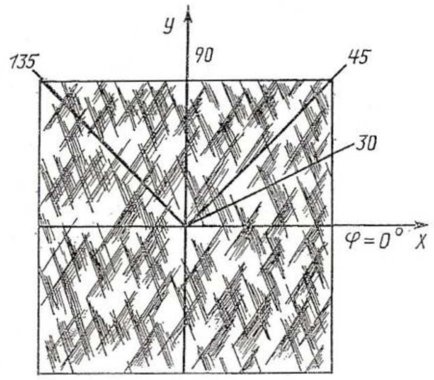


*Fig. I.* Cross-section orientation on the surface.

From the cross-sections shown in this figure we can determine: at $\varphi = 0°$ – the quadratic mean value ($\sigma$), the zero sum ($n$), and the number of maximums ($m$); at $\varphi = 45°$ and 90° – $n$ and $m$, at $\varphi = 30°$ and 135° – only $m$.

## 4. CONCLUSIONS

The cross-section method for determination of 3D surface roughness parameters using 2D measuring techniques has given good results. The method is fitted best for the irregular surfaces, when the roughness is described as the normal random field. This approach can also serve as a basis to develop methods for the research into the regular surface roughness.

## REFERENCES

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## VIRSMAS RAUPJUMA 3D PARAMETRU NOTEIKŠANA AR ŠĶĒLUMU METODI

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### K o p s a v i l k u m s

Mūsdienu ražošanā ir nepieciešams novērtēt virsmas raupjuma parametrus trijās dimensijās, tomēr, aprīkojums šādu mērījumu veikšanai ir ļoti dārgs un ne vienmēr pieejams. Tādēļ bieži rodas nepieciešamība noteikt 3D virsmas raupjuma parametrus pēc labi zināmajiem profila (2D) parametriem, izmantojot eksistējošo 2D mērīšanas aprīkojumu. Labākais risinājums šai problēmai ir izmantot 3D

raupjuma parametru noteikšanai šķēlumu jeb profilu metodi. Metode uzrāda labus rezultātus arī novērtējot nanoraupjumu. Iespējams aprēķināt sekojošu virsmas raupjuma mikrotopogrāfisko parametru vidējās vērtības: raupjuma augstumu; soļu parametrus un formu. Metode ir paredzēta izmantošanai virsmām ar neregulāru raksturu, bet var tikt pielāgota arī citu tipu virsmām.

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