RIGA TECHNICAL UNIVERSITY
Faculty of Transport and Mechanical Engineering
Mechanical Engineering Institute

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INVESTIGATIONS OF IRREGULAR CHARACTER 3D SURFACE ROUGHNESS PARAMETERS

Field: Mechanical engineering

Subfield: Measurement instrumentation and metrology

Summary of Ph.D. Thesis

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Promotion work for obtaining engineering sciences doctor scientific degree will be defended on 5 july 2011 at 10:00 in the Riga Technical University, faculty of Transport and Engineering Science, to address: Ezermalas street 6K, 405 room.

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Riga Technical University

CONFIRMATION

I confirm that I have worked out the promotion work submitted for consideration to Riga Technical University, to obtain of doctor engineering sciences degree. The promotion work has not submitted to any university for obtaining of scientific degree.

Maris Kumermanis ……………………………. (Signature)

Date: ………………………

The promotion work is written in Latvian language and consists of introduction, 7 chapters, resume, references and appendixes. It is written in 107 pages and contains 39 figures, 35 tables, 3 appendixes and 43 references.

Contents

15. Крагельский И.В., Добычин М.Н., Комбалов В.С. Основы расчетов на трение и износ. – Москва: Машиностроение, 1977. – 526 с.
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determination by cross-sections method. Deducted that this method is suitable form 3D parameters calculations.

4) Defined most important nonstandard 3D surface roughness parameters: Ra_T, H_{max}, M_B, η_u, H, V_u and *Sa*, *St*, *Sds*, *Stp*, *Ssc*, *Vm(h)*. Investigated problems of precision of these parameters – dimensions of measurement areas dimensions and their number. Done parameter calculations using cross-sections method and experimental measurements. Deducted that these parameters are acceptable for surface roughness characterization.
5) Experimental investigations of parameters *Sa* and *Ra* shows that 3D parameters has less relative inaccuracy at he same measuring conditions as profile parameters.
6) Developed methodic for measuring 3D surface roughness parameters using contact type measuring devices.
7) Defined principles of 3D roughness parameters data basis forming. Developed data basis for flat grinded surfaces.

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GENERAL DESCRIPTION OF THE PROMOTION WORK

Actuality of the research

In modern manufacturing it is necessary to estimate surface roughness as spatial object. In promotion work “Investigations of irregular character 3D surface roughness parameters” random processed surface roughness research will be done. Also methodic for measuring 3D surface roughness parameters with contact type measuring devices based on random field theory is developed. Developed principles of forming 3D surface roughness parameters data basis. Presently there is no trusted information about measurements of 3D surface roughness parameters. There is not defined unified approach for 3D surface roughness assessment using contact type measuring devices. There is not confirmed standards about 3D surface roughness problems. Therefore, it is necessary to research those problems.

Target and activities

The purpose of this work is to develop 3D surface roughness parameters measurement methodic and forming principles of 3D surface roughness parameters data basis.
Considering previously mentioned there are raised following goals:

1) Prepare theoretical basis of research using random field theory.
2) Research such significant 3D surface roughness measuring characteristics as necessary number of data points, dimensions of measuring area and their number on surface under research.
3) Perform experiments for examination of theoretical calculations.
4) Define 3D surface roughness parameters, perform theoretical and experimental research.
5) Prepare measuring methodic.
6) Develop data basis forming principles for 3D surface roughness parameters of random processed and coated surfaces.

Research technique

For building up model of irregular character surface roughness and for theoretical research there was used random process and random field theory. Experimental research will be done using Taylor Hobson Form Talysurf Intra 50 and Surtronic 25, and TalyMap Expert data processing software. Experimental data processed using mathematical statistics methods and MatCAD, Graph and AutoCAD software.

Scientific novelty and main results of researches

A scientific novelty and the work performances are:

1) Irregular character 3D surface roughness parameters measuring methodic using contact type measuring devices.
2) Improving of method of 3D surface roughness parameters determination by surface splits.
3) 3D surface roughness parameters precision investigations – determination of necessary number of data points for roughness measurements.

4) 3D roughness parameters data basis forming principles for random processed and coated surfaces, and data basis example for flat grinded surfaces.

Practical importance

Investigations conducted in this work on Investigations of irregular character 3D surface roughness parameters allow to assess random solid surfaces. Developed 3D surface roughness data basis forming principles and data basis example for flat grinded surfaces will give us information about prospective surface roughness and parameters of flat grinded surfaces. Further data basis enforcing will give information about another surface processing methods and surface roughness. And on the other hand – from necessary surface roughness parameters there will be possibility to find surface processing method.

In this work an author protects

1) Irregular character 3D surface roughness parameters measuring methodic.
2) Improving of method of 3D surface roughness parameters determination by cross-sections.
3) Methods for determination the necessary number of data points for measuring surface roughness.
4) Random processed and coated surfaces 3D roughness parameters data basis forming principles.

Approbation of the work

About basic achievements and results of promotion work reports, which got a positive estimation on the followings conferences and seminars, were done:

Latvia:

- Rīgas Tehniskās universitātes 48. starptautiskā zinātniskā konference, 11.10. – 13.10.2007
- Rīgas Tehniskās universitātes 48. starptautiskā zinātniskā konference, 13.10. – 15.10.2008
- Rīgas Tehniskās universitātes 48. starptautiskā zinātniskā konference, 12.10. – 16.10.2009
- 6th International Scientific Conference „Engineering for Rural Development", 24.05 – 25.05.2007, Latvija, Jelgava
- RTU Mehānikas institūta un LNMK apvienotais seminārs, 18.05.2010, Latvija, Rīga

International:

- 7th International Conference european society for precision engineering and nanotechnology, 20.05 – 24.05.2007, Bremen, Germany
- 11th International Research/Expert Conference „Trends in the Development of Machinery and Associated Technology" TMT 2007, 05.09 – 09.09.2007, Hammamet, Tunisia
- XII. International Colloquium on Surfaces, 28.01 – 29.01.2008, Chemnitz, Germany
- 10th Anniversary International Conference european society for precision engineering and nanotechnology, 18.05 – 22.05.2008, Zurich, Switzerland

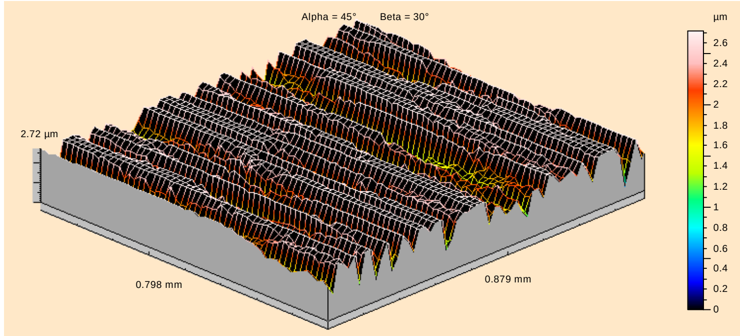

Fig.7.4. Surface truncated by 30% *St*

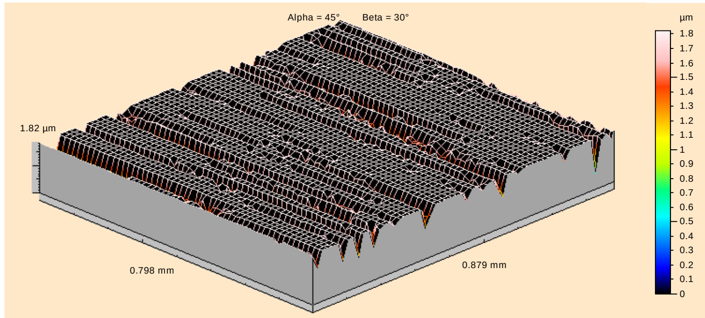

Fig.7.5. Surface truncated by 70% *St*

RESUME

On the promotion work performances it is possible to do the following conclusions:

1) As a result of literature review, the conclusions are done, that the 3D surface roughness problems are investigated partially. Existing standards covers just 2D or profile parameters and their measuring. There is no standardized information about surface characterizing in 3D. Standard ISO/DIS 25178 is still under development.
2) Defined 3D measuring system and its most important characteristics affected to precision of measurement results – number of data points along both axes. Developed three methods for determination of number of data points: using random process theory, graphical approximation and method of determination of number of points at which stabilize the value of the parameters. Done these methods comparing and determine their precision. Given recommended number of data points for irregular character surface roughness.
3) Investigations of 3D surface roughness are done. Defined irregular character surface roughness model with principal data set using random field theory. Observed on the basis of this model developed 3D surface roughness parameters

Table 7.1

3D parameters of flat grinded surface

Parameter	Value	Remarks
Sa	0.628 µm	
St	4.71 µm	
STp	2.9%	1 µm under highest peak
Sds	3903 pks/mm^2	informative parameter
Ssc	0.0279 1/ µm	
Vm	0.00241 mm^3/mm^2	at 0.01 % level

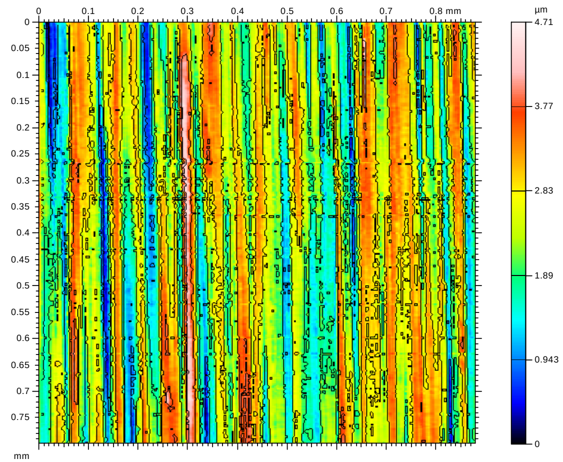

Fig.7.2. Contour map of flat grinded surface

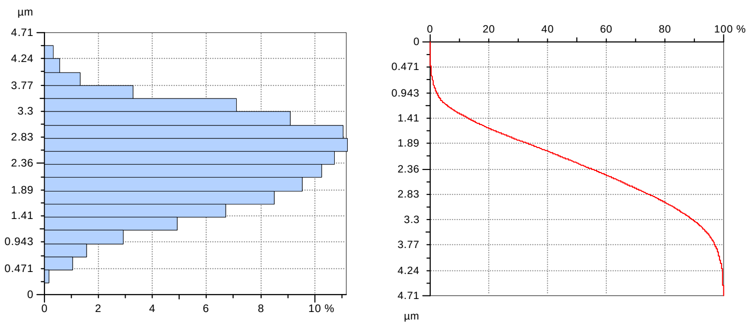

Fig.7.3. Height distribution and Abbott – Firestone curve

- 4th International Conference „Mechatronic Systems and Materials" MSM 2008, 14.07 – 17.07.2008, Bialystok, Poland
- 9th International Conference of the european society for precision engineering and nanotechnology, 02.06 – 05.06.2009, San Sebastian, Spain

Publications:

The conducted researches and elaborations results had been published:

1. Rudzitis J., Kumermanis M. Determination of surface roughness micro topographical parameters on method of indirect measuring// Proceedings of 7th International Conference european society for precision engineering and nanotechnology. - Bremen, Germany, 2007. – pp. 313-316.
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Thesis content and structure

The promotion work consists of introduction, 7 chapters, resume, references and appendixes. It is written in 107 pages and contains 39 figures, 35 tables, 3 appendixes and 43 references.

CONTENT OF THE WORK

Introduction

For successful assessment of random solids surfaces today it is not enough to characterize it with profile or two dimension (2D) measuring methods. It is necessary to use methods based of surface spatial (3D) description.

Chapter 1. REVIEW OF SURFACE ROUGHNESS INVESTIGATIONS

1.1. Surface roughness and classification of rough surfaces

Observed surface micro topography definitions. What is surface roughness and what we understand with it? Surface roughness classification using probability theory will be done. Give examples of random processed 3D surface roughness.

1.2. Surface roughness parameters data basis

For successful surface roughness characterization it is not enough to characterize it with one parameter (traditionally *Ra* – profile deviations from mean). It is necessary to complex characterizing of surfaces, using groups of parameters. For characterization visualization roughness data basis can be used. Analysis of existing data basis [15, 13, 20, 1, 2, 3, 4, 9, 10, 7, 18, and 5] shows that there is not unified (general) approach for characterizing random processed surfaces. Some of observed data basis are growled out-of-date, composed using vintage measuring devices. Values of parameters had relatively large-scale dispersions when characterizes one surface processing method. Therefore, it is necessary to develop visually demonstrative, modern random processed 3D surfaces roughness parameters data basis, using modern measuring devices.

1.3. Precision of parameters determination

Measuring surface 3D roughness, similar as in any other measurements, it is necessary to know precision of results, in this case, precision of surface roughness parameters determination. Under this term we understand number of measurements at what can be obtained parameter value with previously designated parameter inaccuracy. Surface roughness parameters determination precision problems are researched rather few [15, 14, 16, 27, and 8]. As precision of surface parameters determination affected many different external, and internal factors then there are researched only several factors or they groups affection on precision of measurement results. Provided investigations of precision had hairy limitedness, they are attached to specific measuring devices or surface groups. However, the same of the provide researches are suitable for further they consummating by using modern measuring devices and data processing software.

characterize surface with parametrical and visual information. But, as it wrote previously the random surfaces can not able to characterize using one and the same parameters.

Therefore, information about surfaces and their roughness is preferable using certain system or algorithm. This problem can be resolved using data basis, where can be done classification of surfaces by they texture and for each group of surfaces given information about roughness.

In general the content of data basis is following:

1) Description of surface processing method. Done short specific processing method characterization: what type of interments and machines are used. Characteristics of the processing methods parameters and prospective surface quality (roughness) observation are done. Also is given information about processing method problems affecting on surface roughness, for example deformations, thermal process e.g.

2) Parametrical information. Define surface roughness parameter for characterizing used production method. In general, there will be used following 3D an 2D parameters: *Sa*; *St*; *Sds*; *Stp*; *Ssc*; *Vm(h)*; *Ra*; *RSm*.

3) Visual information. In data basis will be including following visual information about surface roughness: the axonometric projection; the contour map of surface; the surface autocorrelation function; the height distribution of surface; Abbott – Firestone curve. Also is given information about surface after truncated by 30% and 70% of parameter St.

7.2. Example of data basis of flat grinded surfaces

In data basis example of flat grinded surfaces is given insight into grinding process. Also observed grinding methods and techniques. Observed problems affected surface roughness such as grain geometry, thermal process e.g. As exaple is gived information about roughness specimen Rugotest 107 *Ra* 1.6 measuring results in visual and parametric form:

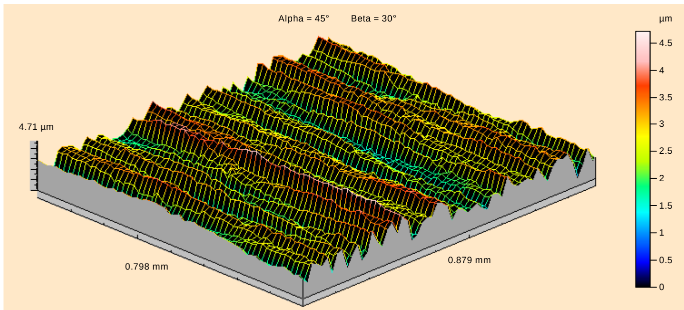


Fig.7.1. Axonometric projection of flat grinded surface

Results processed according to chapter 5.4. Searched parameters relative inaccuracy ε_β less then 5%. Figure 5.2. shows results for flat grinded and spark erosion surfaces. Along horizontal axe replaced quantity L, along vertical axe relative accuracy ε_β .

5.6. Conclusions

Defined general 3D surface roughness parameters they determination using random field theory and surface cross – section method. Also defined parameters developed by Taylor Hobson measuring system engineers. Parameters analytic and experimental comparison for detecting parameters relative inaccuracy is done. It is deducted then these parameters can be used for surface roughness characterization.

Chapter 6. 3D PARAMETERS MEASURING INSTRUCTIONS

1) Set – up measuring device for surface profile (2D) measurement.
2) Measuring surface place on measuring device table so that the measuring surface general direction of process marks will be perpendicular to measuring direction (main axe). If there is no general direction of process marks, then surface orientation can be free.
3) If there is no know surface roughness parameters *Ra* or *RSm* then it determine approximately – using visual aids or another method. If the parameter are known then go to step 7.
4) By approximately determined parameter *Ra* or *RSm* in accordance to standards, for example ISO 4288:1996, determine cut-off length *l* and trace length *L*.
5) Provide testing measurement determine *Ra* or *RSm* value.
6) Verify if obtained *Ra* or *RSm* value corresponds to step 4 mentioned requirements. If value mismatches, then return to step 3.
7) Taking profile chart, determine *RSm* value.
8) Calculate mean number of steps on cut-off length:

$$N_l = \frac{l}{RSm}$$

9) Multiply obtained N_l with number of data points defined for observed surface roughness type and obtain necessary number of data points per both axes for 3D surface roughness measurement.
10) Set-up measuring device for 3D surface roughness measurement. Set the measuring area dimensions and number of data points per both axes. Provide measurement.
11) Using data processing software, for example TalyMap Expert, open the obtained file of measurement results and provide processing of results.

Chapter 7. 3D PARAMETERS DATA BASIS FORMING PRINCIPLES

7.1. Data basis forming principles

3D surface roughness investigations and characterization using modern measuring devices, for example Taylor Hobson Intra 50, there is practically unlimited chances to

1.4. Parameter measuring methodic

There are several methods for measuring surface microtopograhy. But not one of methods is suitable for all-purpose surface roughness characterization. Methods differs between each other not only with used working principles, but also with resolution, measurement time, dimensions of device, costs etc. Dispersion of measurement results measuring one and the same surface by different methods can reach even 80%.

When it is chosen measuring method (device), it is necessary to use some measuring methodology for obtaining real 3D surface roughness parameters. As in previously review of investigations also here is observed fundamental differences between several measurement methodologies [19, 10, and 15]. If the profile methodologies are defined by standards, then 3D parameters measurement problems are not surveyed in any official standard. 3D parameters determination methodologies are derived from profile parameters methodologies. There is not clearly defined such fundamental measurement parameter choosing as number of data points.

1.5. Basic tasks of study

The review of literature allows starting the main task of the thesis:

- Development of 3D surface roughness parameters measuring methodic;
- Determination of 3D parameters their analytical and experimental assessment;
- Using the developed methodic in solid surfaces 3D roughness investigations;
- Summarize measurements results in the 3D surface roughness data basis.

Chapter 2. ANALYSIS OF 3D SURFACE ROUGHNESS MEASURING SYSTEM

2.1. System working principle and the number of data points

In the 3D measurement of a plane or cylindrical surface, a certain number of profiles parallel to the main axis of the sample must be collected. The surface displacement is in two orthogonal directions (Fig. 2.1): *X* - *Y*. In the *x*-direction the data is collected with Δx sampling step and *Nx* number of data points; in the *y*-direction the lines are on Δy step apart and there are *Ny* lines [10]. Data are stored on a disk as they are obtained in the form of binary file. Each data point is stored in two bytes. When data collection is over there is a matrix representing the surface made up of $Nx \times Ny \times 2$ bytes.

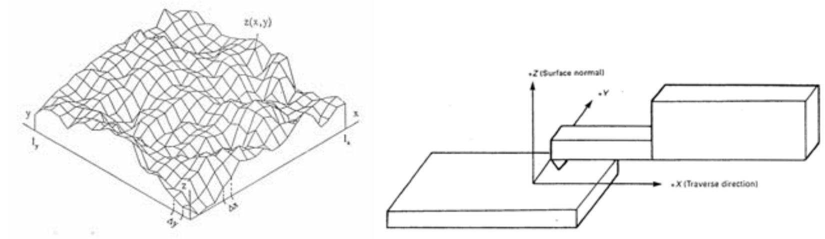


Fig.2.1. 3D measurement system

The number of points is a fundamental choice for the data analysis. Number of data points must be optimal. Slight number of data points leads to incorrect results and increase their distribution amplitude, but too large number of data points does not enlarge range of fundamental information, but substantially increase measuring time

Therefore, we must find optimal number of data points per each surface processing method. Surface benchmarks of following surface specimens will be studied:

Flat grinding – Rugotest 104 (ISO/DIS – 2632);
Spark erosion – Rugotest 107 (ISO/DIS – 2632);
Shouted – Rugotest 3 (ISO/DIS – 2632).

2.2. Determination of number of points with the random process theory

Surface geometrical description is relatively complicated, because surface asperities are placed in various height and they has random configuration. For solving this kind of problem we must use models of surface roughness. There are many surface models, suppose asperity form as geometrical elements: sphere, cone, truncated cone, and cylinder e.g. But the real asperities had substantial deviatons and their character is irregular.

It is proved [20] that the irregular character surface roughness can be described with random functions. It is very important in practice because in most cases the roughness of mating machine parts forming moving and fixed conjugations is irregular. Irregular surface roughness is expressed by a random process *h(x)* which correlation function: $K(\tau)$ (τ - distance between surface points).

If the random process correlation function is

$$K(\tau) = \sigma^2 \rho(\tau), \tag{2.1}$$

where σ – mean quadratic deviation of random process, μm *h(x)*;
$\rho(\tau)$ – fixed correlation function ($0 \le \rho(\tau) \le 1$)

then we can deducted, that the basic information about surface roughness characteristics in height comprised only one parameter σ which can be replaced with *Ra* – profile deviation from mean.

In general the correlation function can be determined by various method's, here we will use only one method – correlation function assessment by using so called special points of profile charts (Fig. 2.2.). These points are: intersections *n(0)*, local maxima *m* and bending point's *s*.

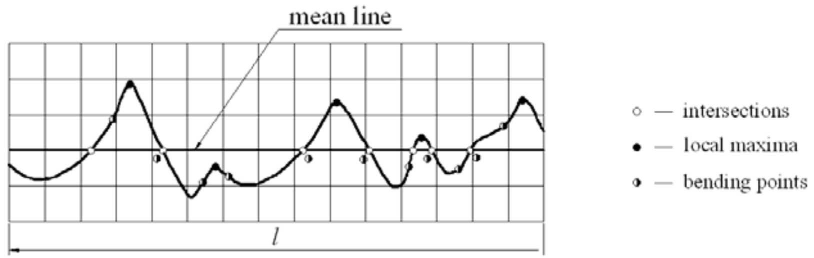


Fig.2.2. Special points of surface profile

5.3. Investigations of 3D parameters

Investigated in chapter 5.1 defined parameters. By chapter 4.3. given instruction calculated parameters Ra_T, H_{max}, M_B, η_u, H, V_u values and provide compared with measured parameters *Sa*, *St*, *Sds*, *Stp*, *Ssc*, *Vm(h)* values. Goal of this investigation is to ass's parameters suitability for 3D surface roughness characterization.

Overall results accordance are rated as good, excepting parameters, characterizing density of peaks M_B and *Sds*. In this case problem occurs to surface summit definition. As it shows researcher investigations [10, 14, 17, 12] then there is various summit definitions and between these definitions is fundamental differences. In that case parameters M_B and *Sds* deem as informative.

5.4. Statistical processing of results of measurements

For detecting random variable distribution rule, it is necessary to use wide range statistical information, often several hundreds of measurements. But in practice this information are restricted to two – three tens measurements, sometimes still les. It is fetter with experiments costliness and complexity. This type of information is unsatisfactory for founding unknowing random variable distribution rule. However, this statistical information can be used and processed for obtain certain information about random variable. For example, on restricted statistical information base it is possible to approximately determine general random variable numerical characteristics: mathematically anticipated value, dispersion, sometimes – upper moments. In practice often occurrence that the random variable distribution rule is previously known, then it is necessary to found just some rule parameters. For example, if we know that the random variable distributes per Gaussian rule, and then data processing goal is to find two parameter *m* – mathematical anticipated value and σ – quadratic mean deviation

5.5. 3D parameters measurements of random processed surfaces

The goal of this chapter is to check the parameters *Ra* and *Sa* determination precision interconnections given in chapter 5.2. Done profile *Ra* measurements at random trace length *L* values and surface *Sa* at random square form measurement areas side dimension *L*.

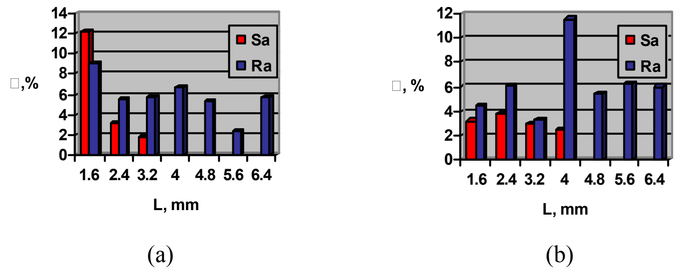


Fig.5.2. Parameter *Ra* and *Sa* relative inaccuracy: flat grinding (a) and spark erosion (b)

5.2. 3D parameters determination precision

Experimental surface roughness research is tightly related with task about choice of number of measurements of the surface under research. In fact, as the number of measurements is greater, as precisely parameter values can be obtained. But in practice, number of measurements is limited; therefore it is necessary chose an optimal area dimensions.

For the determination of number of measurements can be used random field theory method. If the rough surface is described with normal random field, then it is possible to calculate necessary number of measuring areas [20]. For example, number of measurements of parameter Ra_T:

$$n_{Ra_T} = \frac{\pi t_\beta^2}{4\varepsilon^2 c\alpha_1 L^2}, \tag{5.1}$$

where t_β – tabular value [20];
ε – relative inaccuracy [20];
c – anisotropy parameter (3.3);
L – measuring trace length [22].

If the surface is isotropy (c = 1) then:

$$n_{Ra_T} = \frac{\pi t_\beta^2}{4\varepsilon^2 \alpha_1 L^2}, \tag{5.2}$$

Performed expression (5.2) comparing with number of profile *Ra* measurements [20] we obtain:

$$\frac{n_{Ra_T}}{n_{Ra}} = \sqrt{\frac{\pi}{2}} \bullet \frac{1}{\sqrt{\alpha_1} L} \tag{5.3}$$

From (5.3) follow that in given 3D parameter measuring conditions it is necessary at least 8 times less measurements. Therefore, if for profile parameter *Ra* is necessary trace length consisting at least 8 cut-offs, then for Ra_T only one square form measurement area with side length equal to one cut-off length. Fig 5.1. shows above mentioned interconnection.

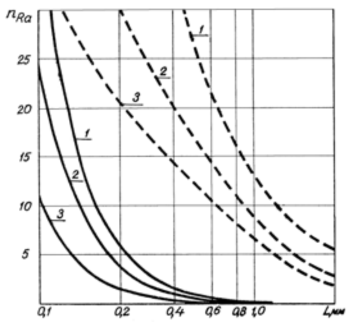


Fig.5.1. Number of parameters *Ra* and Ra_T measurements at (ε = 0.05; β = 0.9):
1 - *Ra* 2,51 $\mu м$; 2 – *Ra* 0,98 $\mu м$; 3 – *Ra* 0,56 $\mu м$
(- - - for profile; ____for surface)

For determining the correlation function it is necessary to found the type, and approximation function. It can be done by two parameters:

$$\lambda = \frac{E\{n(0)\}}{E\{m\}} \;;\; \lambda_s = \frac{E\{n(0)\}}{E\{s\}} \tag{2.2}$$

witch values are in range: $0 \le \lambda \le 2.0$; $0 \le \lambda_s \le 1.0$.
Knowing these parameters, from Fig.2.3, can determine correlation function type [20]

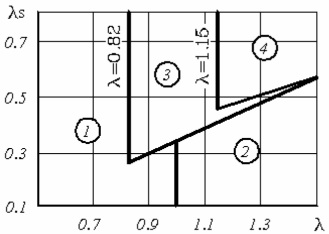


Fig.2.3. Correlation function types

As example, showed determination of number of data point for surface roughness specimen Flat grinding – Rugotest 104 with *Ra* 1.6.

1) After processing of profile chart (according to [19]) the following output data were obtained:

Ra = 1.57 µm; *n(0)* = 25; *m* = 37; *s* = 47.

2) Determine by the formula (2.2) the parameters of the correlation function, needed for the determine of the correlation function type

$$\lambda = 0.68\,;\ \lambda_S = 0.53$$

3) These values corresponding to the first type of correlation function [2] with the parameter α_H, area of the value λ and fixed correlation function interval τ_{KH}

$$\left(1+\alpha\tau^2\right)^{-1};\ \alpha_H = \frac{1}{2};\ 0 \le \lambda \le 2$$

4) Calculate correlation intervals τ_{KH} and τ_K [20]:

$$\tau_{KH} = \frac{1}{\sqrt{2}} \approx 0,71\ mm\ ;\ \tau_K = \frac{\tau_{KH}}{n(0)} = \frac{0,71}{25} = 0,028\ mm \tag{2.3}$$

5) Calculate *RSm* (mean spacing) of the profile on the sampling length

$$RSm = \frac{2}{n(0)} = \frac{2}{25} = 0,08\ mm \tag{2.4}$$

6) Number of points along the sampling length determined by the following

$$k = \frac{l}{\tau_k} = \frac{0,8}{0,028} = 29 \text{ points} \tag{2.5}$$

7) Consequently, the number of spacing on the sampling length

$$z = \frac{l}{RSm} = \frac{0,8}{0,08} = 10 \text{ steps} \qquad (2.6)$$

8) Number of uncorrelated data points on one spacing

$$Ps = \frac{k}{z} = \frac{29}{10} = 2,7 \Rightarrow 3 \text{ points} \qquad (2.7)$$

In a similar way it is possible to find a number of data points for any surface.

2.3. Determination of number of data points using the graphical approximation

Another method for determining the number of data points is to describe the roughness using the graphical approximation. In this case, from the surface roughness profile charts are taken asperity with the most noticeable spacing *RSm* and the most complex structure. There is searched for the number of data points at which the total deviation of approximated roughness height *ha* from the real height *hr* is less than 5% (hr – ha ≤ 5%) (Fig. 2.4).

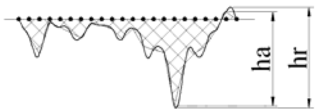


Fig.2.4. Approximated height *hr* and real height *ha* of roughness

Figure 2.5.a shows real roughness, 2.5.b shows roughness appearance (shade area) described with three points, 2.5.c roughness described with 10 points, but 2.5.d with 22 points.

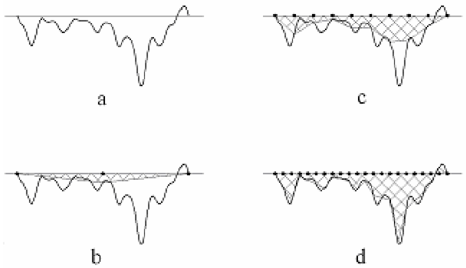


Fig.2.5. Roughness approximation at different values of point number

2.4. Number of data points at which stabilize the value of the parameters

In this case, will determine the number of data points at which the stabilizing value of, for example, the parameter *Ra*, and permissible deviation is 5%. For determination will be undertaken surface roughness profile charts, repeatedly in the same place at different number of data points on cut-off length. The measurement results are shown in Figure 2.6. Horizontal axis is the number of data points, along the vertical axis, value of the

from anisotropy surfaces to isotropy and contrariwise, thereby embrace amount class of surface roughness. In this event are fore values, whose determining needs two surface splits.

4.3. Instruction of 3D roughness parameters determination

For surfaces roughness with direct anisotropy can be used following instruction for 3D parameters determination [21]:

1) Set the surface roughness parameters measuring regime in measuring device, perpendicular to benchmarks.
2) Taking experimental profile charts, determine n_1 and m_1. Define measuring length L from, for example [19].
3) Processing measurements and calculate mean values of parameters *Ra*, n_1, $n(45°)$, m_1.
4) Calculate value of parameter of anisotropy c.
5) On basis of parameters *Ra*, n_1, m_1 and c calculate necessary 3D surface roughness parameters.

4.4. Conclusions

Analysis of surface roughness shows, that is possibility to form system of data output for determination of micro topographical parameters and methodic for any type of surface roughness, using surface cross sections. On basis of cross section parameters mean values *Ra*, n_1, m_1 and c can calculate necessary 3D surface roughness parameters.

Chapter 5. 3D PARAMETERS AND THEIR DETERMINATION PRECISION

5.1. 3D Parameters

There is created many various 3D surface roughness parameters, but none of them are not to be able fare and wide to define any surface. There are some limitation of parameters usage, as parameter values are scale dependent, dependent from measuring external and internal conditions. Parameters often have different definitions, what reduces to problem of parameter interpretation.

In this chapter investigations of 3D roughness parameters will be done. Showed parameters definitions by random field theory and Taylor Hobson measuring system developers defined [10]. General 3D surface roughness parameters for characterizing irregular character surface roughness, also surfaces contact process and wear are following:

Ra_T; *Sa* – arithmetic mean deviations from the mean;
H_{max}; *St* – total height of the surface;
M_B; *Sds* – density of peaks;
η_u; *Stp* – bearing ratio at a given depth;
H; Ssc – arithmetic mean curvature to the tops;
V_u; *Vm(h)* – material volume at depth *h*.

Prior to research all micro topographical parameters, based on quantities $h_1, h_2, \ldots, h_6$, we must know six-rank density and them mutual distribution, defined by matrix [21]:

$$\begin{vmatrix} \sigma^2 & 0 & 0 & K_{20} & K_{11} & K_{02} \\ & -K_{20} & -K_{11} & 0 & 0 & 0 \\ & & -K_{20} & 0 & 0 & 0 \\ & & & K_{40} & K_{31} & K_{22} \\ & & & & K_{22} & K_{13} \\ & & & & & K_{04} \end{vmatrix} \qquad (4.1)$$

This matrix contained system of input data for describing rough surface.

One surface cross-section allows to makes three equations. For determining nine values *Kij* it is necessary five surface cross-sections. After solving system, contained nine equations, can obtain correlation expressions between 3D parameters and cross-section parameters. Anent to these five surface cross-sections (Fig.4.1) we can determine at $\varphi = 0°$ - σ, *n* and *m*; at $\varphi = 45°$ and 90° – *n* and *m*, at $\varphi = 30°$ and 135° – only *m*.

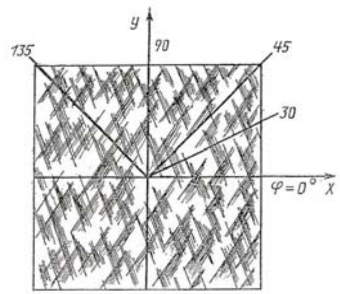


Fig.4.1. Cross-section orientation on the surface

4.2. Special events of rough surfaces

General event of surface anisotropy. Characteristics of this event roughness parameters are depend of surface split direction. There is no dominated roughness direction or it has a complicated type. Those surfaces are forming in face turning and honing process. The system of data output in this event form nine values. To determine those values is necessary five surface splits

Surface roughness with direct anisotropy. Those surfaces are with typical traces of tool and those proper two mutually perpendicular surface roughness directions: cross direction and longitudinally direction of roughness. Those surfaces forming in planed, turning, milling and circular grinding process. The system of data output in this event form six values. To determine those values is necessary three surface splits.

Extended anisotropy area – special event of anisotropy roughness. Of analytical opinion, gainfully anisotropy roughness sees as extended occasional isotropy area. This let easy cross

parameter *Ra*. Measurement error in this case amounts to 2% + 6 nm. As you can see from the Figure 2.6, then the parameter *Ra* begins to stabilize when the number of points is 30.

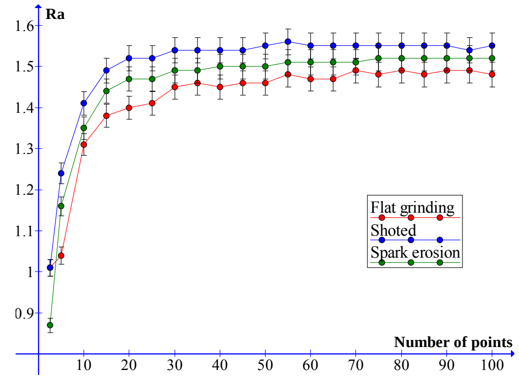


Fig.2.6. *Ra* values at different number of data points

2.5. Conclusions

Provided investigations in this section give following results:

1) Defined 3D surface roughness measuring system, using contact type measuring devices. Deducted that the mist important characteristic affected on results precision is number of data points in both measuring directions.
2) Developed three methods for determination of number of data points per roughness mean step *RSm* for irregular character surface roughness. Table 2.1. shows the number of data points obtained from these methods for three types of surfaces. Also is given dispersions of these methods.

Table 2.1

Number of data points

Specimen	Method					
	Random process theory		Graphical approximation		Value stabilize	
	points	error	points	error	points	error
Flat grinding	3	88%	22	5%	30	2%
Spark erosion	5	23%	14		20	
Shot	5	8,4%	14		20	

3) From table 2.1 are seen, that the random process theory method gives relatively big dispersion. It can be explained, that the full correlation interval was used for determining number of uncorrelated data points. Graphical approximation and parameter value stabilize method shows similar results and slight errors. Taking into account the results of last two methods it can be recommend that for irregular character 3D surface roughness measurements use unitary number of data points – 22 points per roughness mean step *RSm*. Dispersion at this number of data points will be 2 … 5%.

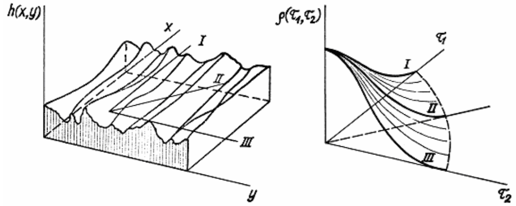
4) Analysis of the number of data point determination types shows that it is possible to determine the number of data points for specific processing type, using the roughness structure. Determination of data points with the correlation functions does not give the necessary result, what is explained with the fact that the actual surface roughness is with a significant deviation from the theoretical model. The method of graphical approximation and the number of data points at which stabilize the value of the parameter *Ra* method produce sufficient good match. Consequently, the number of points we can determine as the average value between results of these two methods. In the case of surface grinding, we can take 26 points on the roughness spacing. This condition is valid for both axes x and y.

Chapter 3. THEORETICAL APPROACH TO 3D SURFACE ROUGHNESS

3.1. General definitions and theoretical model of micro topography

As it mentioned previously, that for complete surface roughness description it is not enough to know only profile (2D) information – it is necessary to use 3D methods.

Irregular character surface roughness is expressed by a random field $h(x, y)$ (Fig.3.1.) of two variables x, y which are Cartesian coordinates of a surface point, where the height of roughness asperity $h(x, y)$ has a normal probability distribution. Assume that the correlation function of the random field is uninterrupted and has uninterrupted derivatives.



a b

Fig.3.1. Representation of surface roughness model (a) and correlation function (b).

3.2. The principal 3D surface roughness parameters

The principal parameters are those which contain information concerning the basic properties of surface roughness. If the surface roughness is described with random field then the principal 3D surface roughness parameters are: *Ra*, σ and the mean spacing along the x and y axes: S_1m and S_2m. Also in this case we can use special points (see chapter 2.2.) just determined form mean plane, not from mean line. By these points it is possible to determine the anisotropy parameter c:

$$c = \frac{E\{n_2(0)\}}{E\{n_1(0)\}} = \frac{E\{S_1m\}}{E\{S_2m\}} \qquad (3.1)$$

Range of parameter c is in interval from 0 till 1. At $c=1$ field is isotropic, at $c=0$ fields is maximally extended.

3.3. Correlation matrix

Investigations of such surface roughness characteristics as local maxima, bending, and slope are connected with derivations of random field function. If designate normal random field as $h_1=h(x,y)$, then it derivations as h_2, h_3, h_4, h_5, h_6 are following:

$$h_2 = \frac{\partial h(x,y)}{\partial x}; \quad h_3 = \frac{\partial h(x,y)}{\partial y}; \quad h_4 = \frac{\partial^2 h(x,y)}{\partial x^2}; \quad h_5 = \frac{\partial^2 h(x,y)}{\partial x \partial y}; \quad h_6 = \frac{\partial^2 h(x,y)}{\partial y^2} \qquad (3.2)$$

Because the random field derivations also formed random field, then their cumulative distributions $h_1, h_2, ..., h_6$ can describe with correlation matrix:

$$\begin{vmatrix} k_{11} & k_{12} & k_{13} & k_{14} & k_{15} & k_{16} \\ & k_{22} & k_{23} & k_{24} & k_{25} & k_{26} \\ & & k_{33} & k_{34} & k_{35} & k_{36} \\ & & & k_{44} & k_{45} & k_{46} \\ & & & & k_{55} & k_{56} \\ & & & & & k_{66} \end{vmatrix} \qquad (3.3)$$

where k_{ij} – quantities $h_1, h_2 ..., h_6$ correlation moments.

3.4. Conclusions

Theoretical investigations of 3D surfaces roughness shows that:

1) It is possible to define irregular character anisotropy surface theoretical model as homogeneous random field and define its output data system.
2) Principal 3D surface roughness parameters are *Ra* or σ (*Rq*) and the mean spacing along the x- and y- axes: S_1m and S_2m, determined form mean plane.
3) Observed given roughness model probability characteristics: random quantities cumulative distribution and it derivations describing with correlation matrix.
4) Defined rough surface anisotropy parameter c, determinable as spacing S_1m and S_2m relation.

Chapter 4. DETERMINATION OF 3D SURFACE ROUGHNESS PARAMETERS BY CROSS-SECTIONS

In this chapter method of 3D surface roughness parameters determination by cross-sections is studied. Defined surface cross-sections parameters. Studied surfaces in general case and defined special events of rough surface.

4.1. The principal data

All information included in the input data must be minimal per size, but at the same time enough for determining height, step and form parameters. In that case it is necessary to know the two arguments function $h(x, y)$, describing micro roughness as three dimensional object, its first and second derivations (3.2) For example, quantity h_1 is used for determining roughness height parameters, h_2 and h_3 for surface gradient assessment, h_4 and h_6 – peak roundup.