3D Characterization of Engineering Surfaces

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Abstract
Operational characteristics of technical surfaces are greatly influenced by microtopographical features. In last decade there was a significant advance in 3D characterisation of surface microtopography. This study presents some results our team have achieved in this field of 3D standard characterisation, new techniques to analyze the asperities, the contact behavior of real surfaces and the changes of surface microtopography in wear process.

Keywords: microtopography, asperities, contact behavior, wear, peak radius, slope angle

1. Introduction

The operation, reliability, and lifetime of parts produced in different ways greatly depend on the quality of machined surfaces as well. Higher quality criteria require adequate accuracy of manufacturing as well as a deeper analysis of surface microtopography. Surface quality includes surface microgeometry discrepancies, such as roughness and waviness as well as the physical and chemical conditions of the surface layer, the latter including plastic deformation in the course of machining, hardness of the surface layer, residual stress, texture, and chemical composition.

Traditionally and in accordance with Hungarian and international standards, the microgeometry of operating surfaces has been characterized by two dimensions. Demand for 3D processing was presented as early as the second half of the 80s. In the first half of the 90s, missing conditions till then, such as computers of adequate speed of operation and processing softwares became increasingly available, making it possible to realize 3D processing.

Severeal engineering components transfer load under sliding contact. Between two sliding bodies there are contact over only small areas of the nominal contact are due to the surface microtopography. The nominal contact pressure is thereof much smaller than the real contact pressure acting over the real contact areas inside the contour contact areas. To evaluate the contact parameters different numerical methods were used in the past decades. The latest ones can consider the real surfaces based on measured surface roughness data.

In the course of friction and wear processes, surface microtopography plays a dual role. On the one hand, it affects the contact and temperature conditions occurring between the contacting surfaces, which determine the tribology process together with the wear particles in between the surfaces; on the other hand, it undergoes significant changes in accordance with the wear mechanism operating between the surfaces. Therefore the analysis of microtopography provides opportunities for identifying and understanding more deeply the wear mechanism.

The aim of the present material is to review the research results of the team of the authors [2-7], working on this field since 1990, implementing a 3D surface roughness measuring technique, preparing different algorithms to evaluate and substitute microtopography in order to learn the tribological behaviour of measured surfaces and to optimize the wear performance of them.

2. Parametrical characterization of surface microtopography

2.1. 3D surface roughness parameters

Professional literature sources provide an overview of topographic parameters [1]. 3D topographic characteristics can be classified as follows on the basis of their geometric information content:

2.1.1. Amplitude (or height) parameters

- Aritmetic Mean Deviation of the Surface, $\mathbf{S_a}$. 2D equivalent: R_a.
- Root - Mean – Square Deviation of the Surface, $\mathbf{S_q}$. 2D equivalent: R_q.
- Ten point height of the surface, $\mathbf{S_z}$. 2D equivalent: R_z.
- Skewness of Topography Height Distribution, $\mathbf{S_{sk}}$. 2D equivalent: R_{sk}.
- Kurtosis of Topography Height Distribution, $\mathbf{S_{ku}}$. 2D equivalent: R_{ku}.

2.1.2. Interstitial parameters (describing horizontal topographic features)

- Density of Summits of the Surface, $\mathbf{S_{ds}}$. 2D approximate: C number of peaks.
- Texture Aspect Ratio of the Surface, $\mathbf{S_{tr}}$. Only to be interpreted in 3D. To be determined by the surface autocorrelation function (AACF).
- The Fastest Decay Autocorrelation lenght, $\mathbf{S_{al}}$. Only to be interpreted in 3D. S_{al} is the shortest autocorrelation length where AACF decreases to 0.2.

2.1.3. Hybrid (or complex geometrical) parameters

- These parameters can be calculated using height and interstitial parameters.
- Root - Mean – Square Slope of the Surface, $\mathbf{S_{\Delta q}}$. 2D equivalent: Δ_q.
- Aritmatic Mean Summit Curvature of the Surface, $\mathbf{S_{sc}}$. No 2D equivalent.
- Developed Interfacial Area Ratio, $\mathbf{S_{dr}}$. 2D approximate: Lr.

2.1.4. Functional parameters (describing operational characteristics)

- Surface Bearing Index, $\mathbf{S_{bi}}$. No 2D equivalent.
- Core Fluid Retention Index, $\mathbf{S_{ci}}$. 2D approximates: R_k parameters. Geometrically speaking, S_{ci} represents the value of empty volume pertaining to a sampling surface unit of the core zone, as referred to S_q.
- Valley Fluid Retention Index, $\mathbf{S_{vi}}$ **.** It is a parameter similar to S_{ci}. It represents the value of empty volume pertaining to a sampling surface unit of the valley zone, as referred to S_q.

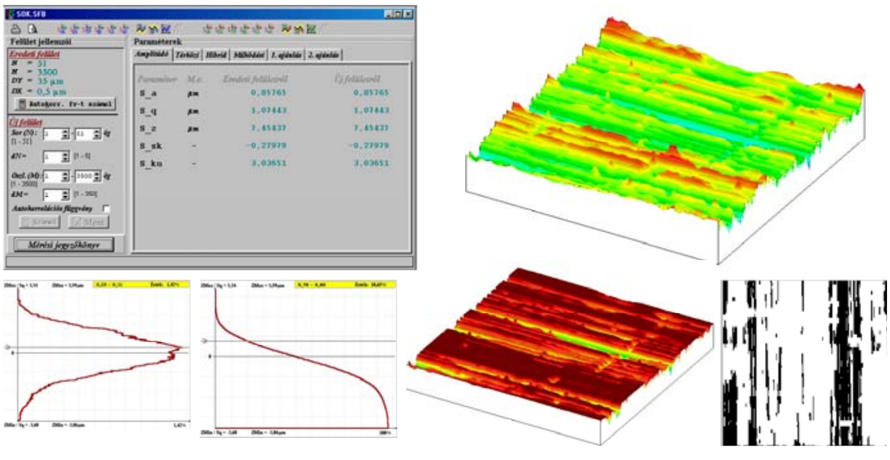

Figure 1. Some options from the parametric and visual services of the Surf 3D program [2]

A software (Surf3D) has been developed to characterize the surface microtopography with more then 25 parameters and with visualization (Figure 1.).

2.2. An overview of tribologically important, informative parameters [1]

2.2.1. Root-Mean-Square Slope of the Surface, $S_{\Delta q}$.

It provides the quadratic mean of the inclination (slope) of surface microtopography within the sampling surface. It is to be interpreted as follows:

$$S_{\Delta q} = \sqrt{\frac{1}{(M-1)\cdot(N-1)}\sum_{j=2}^{N}\sum_{i=2}^{M}\rho_{i,j}^{2}} \qquad (1),$$

where

$$\rho_{i,j} = \sqrt{\left(\frac{\delta\eta(x,y)}{\delta x}\right)^{2}+\left(\frac{\delta\eta(x,y)}{\delta y}\right)^{2}}\Bigg|_{x=x_i,\,y=y_i} \qquad (2)$$

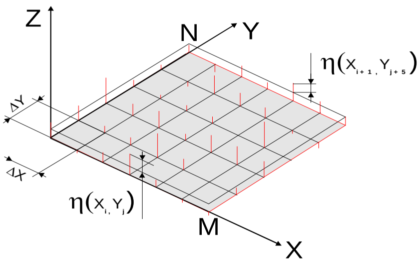

Figure 2. Basic parameters of 3D evaluation of surface microtopography [3]

In Figure 2, M and N are the number of measurement points in directions X and Y, respectively; $\eta(x_i,y_j)$ is the distance of surface point with coordinates (x_i,y_j) from the median plane calculated by the method of the smallest squares.

Some specific values of $S_{\Delta q}$ for surfaces processed by different procedures:

Processing method	***Ground***	***Lapped***	***Spark eroded***
$S_{\Delta q}$ [°]	2.75°…3.40°	5.33°…6.64°	8.65°…10.55°

Table 1. Surface microgeometry slope values for various surfaces

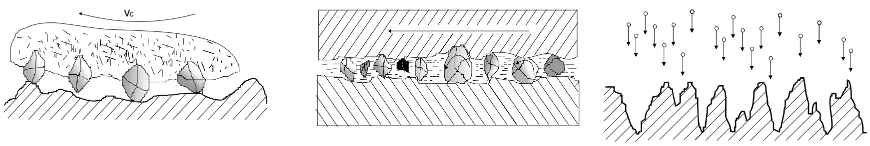

Figure 3. A scheme of the surface transformation mechanism of grinding, lapping, and spark eroding [3]

2.2.2. Aritmetic Mean Summit Curvature of the Surface, S_{sc}.

It specifies the average of main summit curvatures within the sampling surface. As the sum of the perpendicular curvatures of a surface point (e.g. a summit of the surface) is equal to the sum of main curvatures, the average (aritmetic mean) summit curvature of the surface can be specified as:

$$S_{sc} = -\frac{1}{2n}\sum_{k=1}^{n}\left(\frac{\delta\,\eta_k^2(x,y)}{\delta\,x^2}+\frac{\delta\,\eta_k^2(x,y)}{\delta\,y^2}\right) \qquad (3)$$

where n is the number of summits. It has no direct 2D equivalent.

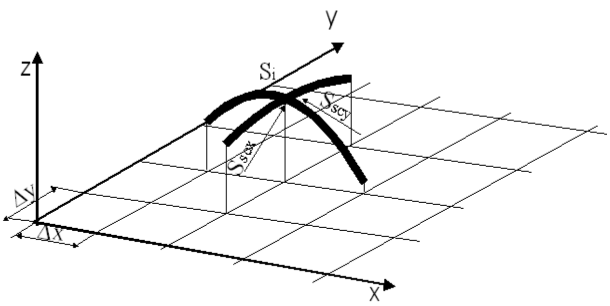

Figure 4. Interpretation of summit curvature of the surface [3]

In Figure 4, S_i is surface summit i; S_{scx} and S_{scy} are its curvatures in x and y directions.

Processing method	**Ground**	**Lapped**	**Spark eroded**
S_{sc} [1/µm]	0.0072…0.008 1/µm	0.0145…0.0188 1/µm	0.0270…0.0292 1/µm
S_{sr} [µm]	124.5…139.8 µm	53.1…68.9 µm	36.9….35.5 µm

Table 2. Values of aritmetic mean summit curvature of the surface for various surfaces

S_{sr} (Aritmetic Mean Summit Radius of the Surface) means the aritmetic mean of the radius of summits of the surface, which is a more obvious and practical measure.

3. Asperity substitution to characterize the surface microtopography

Various shapes of asperities can be observed on the surface when studying the topography of measured rough surfaces depending on machining, operational conditions, etc. These geometric shapes are called roughness peaks or valleys according to their position relative to the median plane. Roughness peaks dominate in contact states.

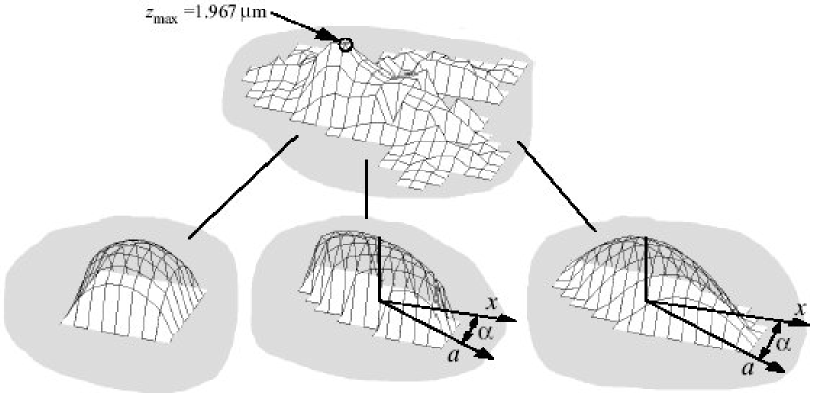

Figure 5. A roughness peak and its substituting surfaces (hemisphere, ellipsoide, paraboloid) [4]

In order to compare various surfaces in terms of constituting roughness peaks, the geometrical features of roughness peaks should be characterized in a similar fashion.

The roughness peaks identified one by one can be substituted by regular geometrical shapes. The parameters of substituting elements may act as new roughness peak features. As in this case roughness peaks are intended to be substituted for contact analysis, it is expedient to substitute them by quadratic surfaces (see Figure 5.).

4. Using slicing technique to analyze the surface microtopography

The concept of asperity is not yet fully clarified in 3D evaluation techniques today. There are different definitions available. On the one hand, this makes it difficult for those involved in the subject to communicate, at the same time indicating that there are a number of opportunities open for asperity analysis. The basic principle resembles to the so-called contour search technique. In terms of our algorithm, an asperity can be defined as a geometric conformation displayed by a connected set of measurement points located over the median plane, at the intersection of another parallel plane.

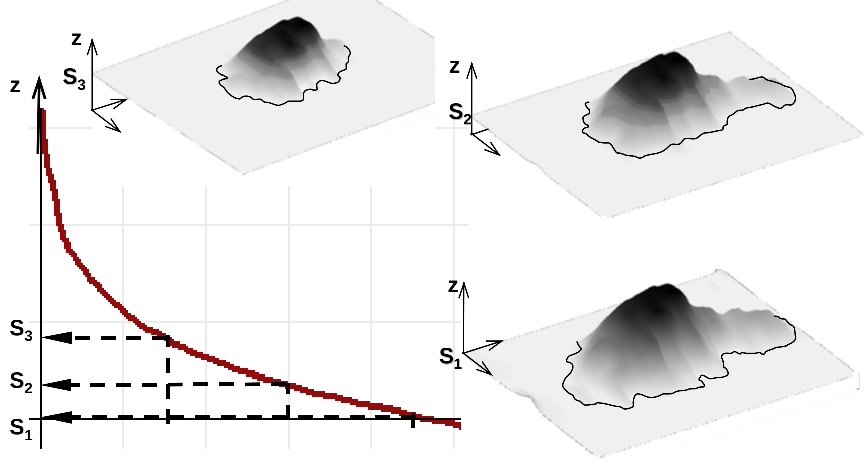

Figure 6. The slicing method [6]

After finding asperities, their characteristics are determined by using the set of measurement points directly. Our earlier investigations showed that the most important parameters characterizing asperities are the peak radius and the peak angle; besides, the entire microtopography is characterized by definition of the orientation angle of asperities. [6]

5. Tribological characterization of surface microtopography

5.1. The contact behavior of real surfaces

The main goal of this analysis is to introduce different substituting surfaces to represent the original asperities and to compare their performance in contact behaviour.

The respective contact states of the original and the substituting rough surfaces are specified in contact with an ideal plane using an approximate algorithm of elastic-palstic contact. The rough surfaces are made of bronze, wheras the ideal plane is made of steel. The test surface (Figure 7a) was produced by grinding. The load (average pressure) is p=10 Mpa. The location of contact areas is shown in Figure 7.

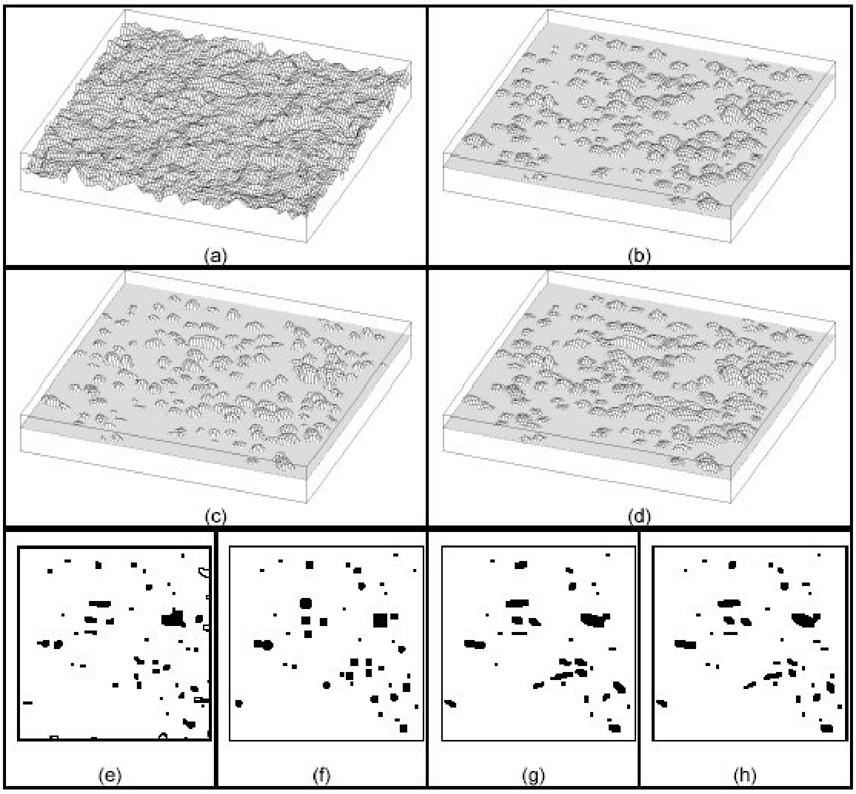

Figure 7. The roughness peaks ((a) original surface, (b), (c), (d) substituting surfaces) and the real contact areas [5]

5.2. Changes of surface microtopography in wear

Our tests were performed on two completely different worn surfaces in order to find out about the characteristics from which conclusions can be drawn to the wear process and to find an explanation for the wear phenomenon generating the surface. The left side of Figure 8. shows the image of a bronze surface sliding dry under low load along a steel track. The original pattern has not yet disappeared from the surface. As a result of wear, a plateau was formed, consisting of many small scratches and some deep groove of wear. This phenomenon can also be observed in Figure 9., prepared by a scanning electron microscope. The right side of Figure 8. and 9. show ceramic surfaces sliding dry on steel under high loads. A tribofilm covered the surface in the course of the wear process. The electron microscopic image clearly shows the tribofilm consisting of small particles adhered to the surface. The wear at the bronze surface results from a predominantly abrasive wear mechanism, while the tribofilm deposited on the surface suggests mixed wear, primarily of the adhasive type.

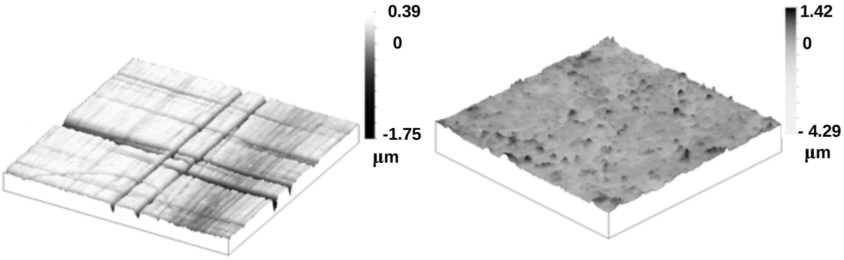

Figure 8. Image of the surfaces roughness measurement (left: a bronze surface worn abrasively; right: worn ceramic surface with tribofilm deposited thereon)

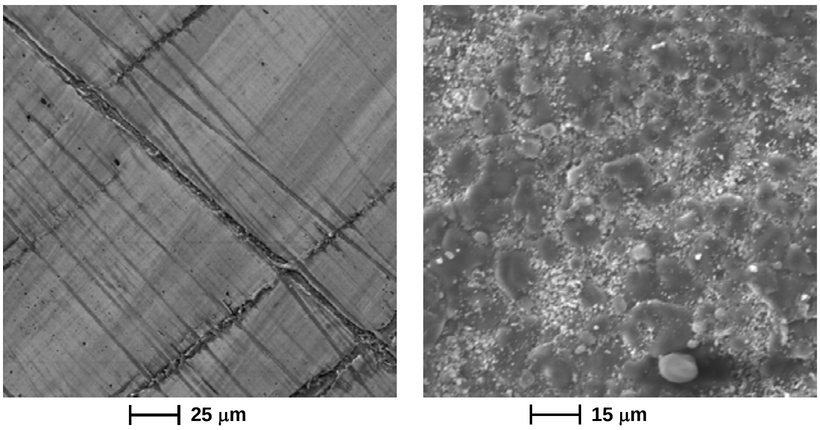

Figure 9. SEM image of the surfaces examined (left: a bronze surface worn abrasively; right: worn ceramic surface with tribofilm deposited thereon)

5.2.1.. Peak radius

The peak radius of asperities is interrelated with the contact conditions of the surface. Figure 10. shows that in the case of the bronze surface, the distribution function extends to a relatively broad range despite the fact that peak points are dominantly located at the height level of the plateau formed. The maximum is at 270 µm, but there are much higher values as well. Also considering the height distribution curve of peak points, it can be stated that surface asperities have a large peak radius and are located within a relatively narrow range, therefore a surface with high load bearing capacity was produced in the course of the wear process. The asperities of the ceramic surface have a similar peak radius although they are located in a relatively broad height range. Here the maximum of the curve is at 180 μm. Therefore the contact conditions of the surface are much less favourable than those of the finely worn bronze surface.

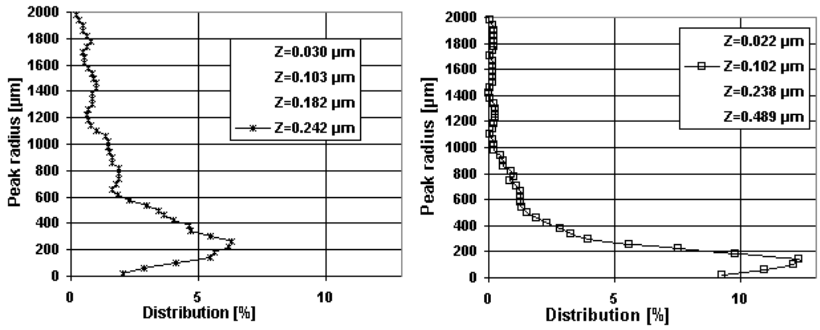

Figure 10. Distribution curve of the peak radius of asperities in direction of the major axis (left: bronze, right: ceramic)

5.2.2. Peak angle

The significance of specifying peak angles is shown primarily in terms of wear behavior rather than contact behavior. It should be noted in relation with both curves shown in Figure 11. that the peak angle of surface asperities is a large obtuse angle. Therefore, when the production of the deep scratches on the bronze surface shown in Figure 8. and 9. are examined, it can be established that deep grooves were not produced by “sharp” asperities – as the peak angle of asperities is a large obtuse angle –, but that their generation can be explained by hard wear particles landing between the surfaces. When examining peak angles, it can be seen that in the case of the bronze surface they take up quite high values in accordance with the smooth plateau-like surface. In case of the ceramic surface, the characteristic peak angle value – the peak point of the distribution curve - shifts towards smaller angles, but it still remains in the range of large obtuse angles.

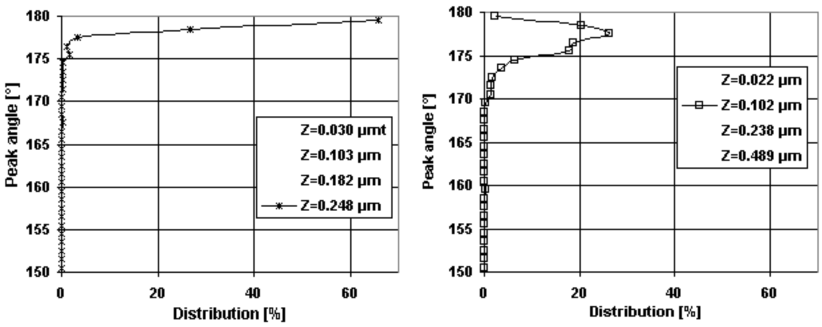

Figure 11. Distribution curve of the peak angle of asperities in two direction

Conclusions, experiences

3D processing of technical surface microtopography provides information on the operational characteristics of surfaces besides their geometry. Such features containing operational information primarily describe the shape of surface microgeometry.

The substituting technique is suitable to identify asperities and to analyze the contact behavior of real surfaces.

The technique using distribution curves developed for characterizing asperities is suitable for studying the wear behavior of surfaces in the course of dry friction as well as for tracing surface changes.

Acknowledgements

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References

[1] K. J. Stout, P. J. Sullivan, W. D. Dong, E. Manisah, N. Luo, T. Mathia, H. Zahouaro (1994), „The Development of Methods for the Characterisation of Roughness in Three Dimensions", Commission of the European Communities.

[2] Kovács,K. Palásti,K.B. Váradi,K.: Microtopographic analysis of technical surfaces by 3D parameters, Gépészet 2000 Konferencia, Budapest, 2000,

[3] Kovács,K. Palásti,K.B. Váradi,K.: Tribological characterization of technical surface microtopography, VII. Tribológiai Konferencia, Budapest, 2000, szeptember

[4] Néder, Z., Váradi, K.: Contact Behaviour of the Original and Substituted Real Surfaces, International Journal of Machine Tools and Manufacture, Vol. 41, Oct-Nov 2001, pp. 1935-1939.

[5] Néder, Z., Váradi, K., Bercsey, T., Palásti, K. B.: Contact and Statistical Analysis of the Asperities of Real Surfaces, Methods and Processes of Development in Mechanical Engineering, Magdeburg, Germany, 19-20 September 2001, pp. 157-163.

[6] Czifra, Á., Váradi, K., Palásti K., B.: Surface microtopography analysis by a slicing method, Gépészet 2004, 4th conference on mechanical engineering, Budapest, Hungary, 27-28 May 2004, p. 676-680

[7] Czifra, Á., Váradi, K., Palásti K., B.: Characterisation of worn surfaces with a slicing method, 8th International Conference on Tribology, Veszprém, Hungary, 3-4 June 2004, p. 150-155