SZENT ISTVÁN EGYETEM

STEEL SURFACE MICROTOPOGRAPHY CHANGES IN THE INTIAL STAGE OF ABRASION PROCESS

Thesis of PhD work

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CONTENTS

# 1. INTRODUCTION AND OBJECTIVES

The designing of the machine parts the main task is to operate reliably in the lifetime. In terms of the traditional design methods we can say to ned to define the connection of the material, geometry and loads:

- according to the material parameters and geometry the loads,
- according to the material parameters and loads the geometry,
- according to the loads and geometry the material parameters can be solved.

In addition to the above design process through to the detailed design, the lifetime achievement of an appropriate examination of the tribological processes needed.

In recent years, we can find a lot of model which determine the surface quality with the help of the roughness parameter. The roughness parameters of the parts changes during the tribological process, so the real contact zone, the heat transfer and lubrication stage changes. To characterise a tribological system researchers developed simulation models or the other hand made tests and use two-dimensional roughness parameters, linear composition studies, micro hardness values and electron microscope images in the process of steady wear stage.

The last 10 years can be observed that the roughness measurement and evaluation researchers widely used in the three-dimensional surface roughness measurement for the detailed evaluation. This system of course does not provide a detailed characterization than the above mentioned tribological tests, however, provides the possibility for knowing the change in certain shapes and wear tested microtopography.

*Objectives*

The aim of my research is to define the roughness parameters modification in the initial stage of the abrasion process.

1. At first step I will develop a truncation algorithm which takes into account the effect of the scratches in a peak zone at the initial stage of wear process

2. The next step I will compare the usability of the profile and the microtopography measurement technology in a case of abrasive worn surfaces.

3. For the validation of the truncation algorithm results I will make a design of experiment and compare the functions witch specified from the simulation model and the DOE.

4., At least I will find a roughness parameters ot parameters that predict the end of the initial stage of wear.

## 2. MATERIAL AND METHOD

In this chapter the truncation algorithm and the design of experiments are shown.

### 2.1. Truncation algorithm

In case of microtopographies, the truncation algorithm can be used for examining the progressive destruction of the peak zone by roughness parameters.

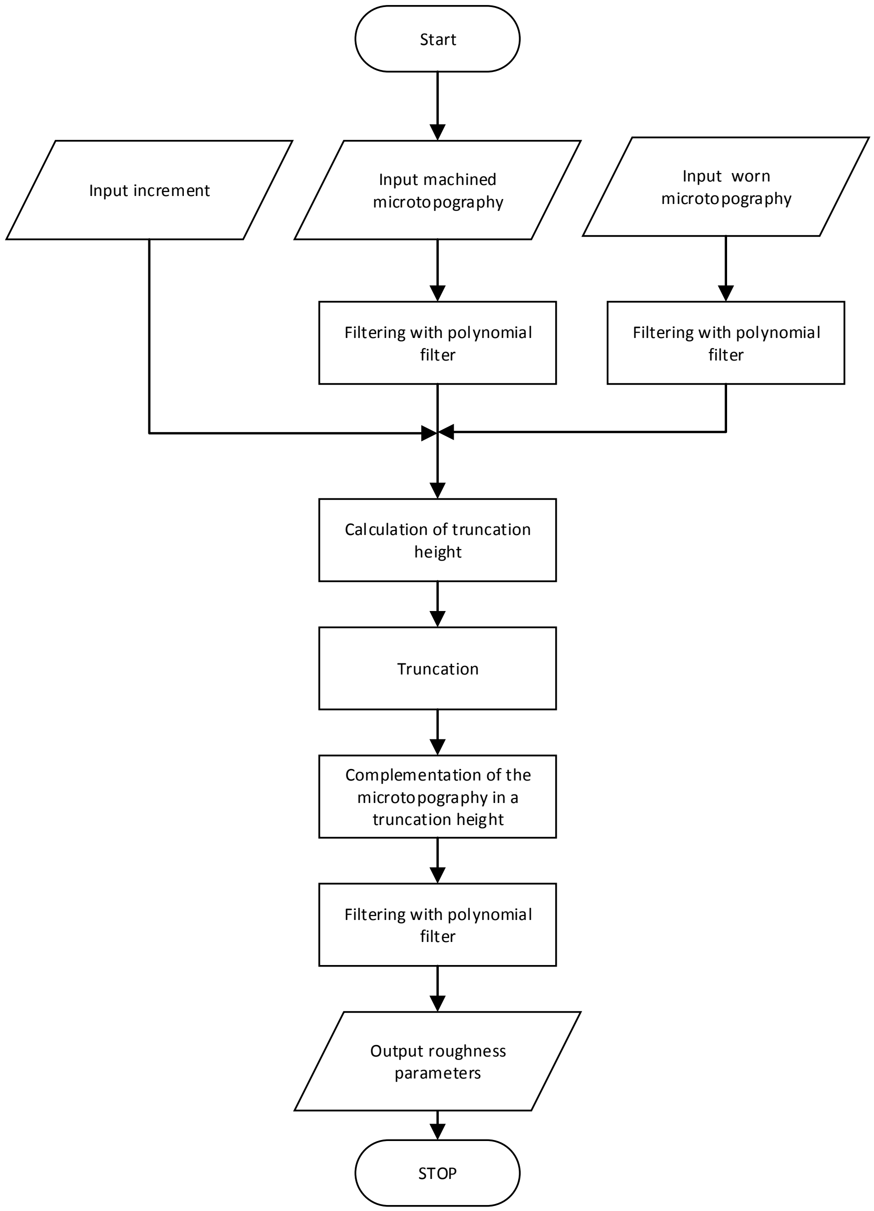



Fig. 1. The flowchart of the truncation algorithm

After reading in the machined surface, the algorithm developed by me (Fig. 1) specifies the material volume to be removed for the total destruction of the microtopography. Then the simulation model determines the truncation heights.

The truncation heights can be determined by two method (Fig. 2):

- according to linear scale,
- according to Abbott – Firestone curve.

Using the second method is a truncation can be implemented where the removed material volume fractions are constant in each step.

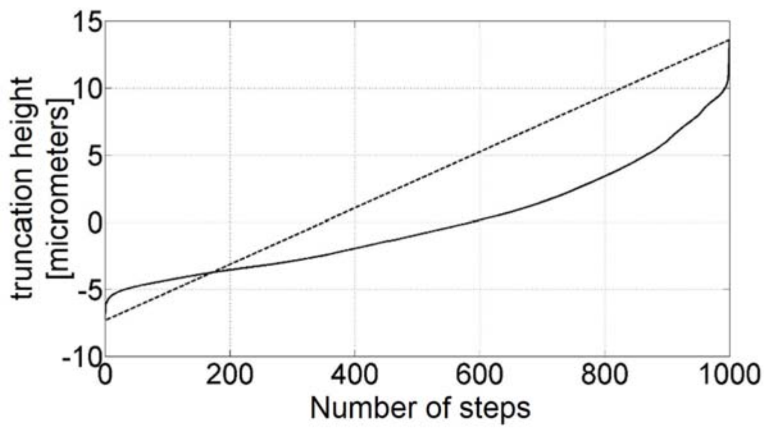



Fig. 2. The relationship between the truncation step and the truncation height in the case of linear and constant removed material ratio method

The points removed cause ruptures in the microtopography. These ruptures are substituted by plane or by fully destroyed microtopography points (Fig. 3).

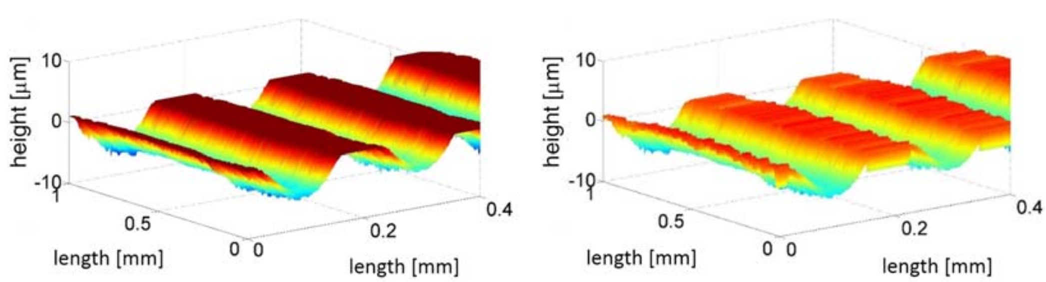



Fig 3. Microtopography patching at a given height by plane and abrasion scratches

In the case of plane patching the results of the algorithm cannot be used perfectly, because the end of the running in stage wear process the Sa and Sq parameters tends to 0 micron, the Ssk parameter trends to minus infinity, and the Sku parameter trends to minus infinite value in the case of oriented microtopography.

The "virtual" microtopography (which generated from measurement results, truncated by Abbott – Firestone curve and patched by abrasion scratches) was filtered by a first-degree polynomial in both directions, retaining both the waviness and roughness characteristics of the measurements.

Afterwards, the results of the algorithm were evaluated using the parameters Sa, Sq, Ssk, and Sku in function of the destroyed volume portion, using equations (1), (2), (3), and (4).

$$Sa = \frac{1}{MN}\sum_{j=1}^{M}\sum_{i=1}^{N}\left|z(x,y)\right| \tag{1}$$

$$Sq = \sqrt{\frac{1}{MN}\sum_{j=1}^{M}\sum_{i=1}^{N}(z(x,y))^2} \tag{2}$$

$$Ssk = \frac{1}{MNS_q^3}\sum_{j=1}^{M}\sum_{i=1}^{N}(z(x,y))^3 \tag{3}$$

$$Sku = \frac{1}{MNS_q^4}\sum_{j=1}^{M}\sum_{i=1}^{N}(z(x,y))^4 \tag{4}$$

### 2.2 Test pieces and the wear experiment

During the tests – where the initial stage of wear was described from several aspects – 1.0503 steel test pieces (supplier: BÖHLER-UDDEHOLM Hungary Kft.) were used in normalized heat treatment state. A revolving knife technology (rpm: 400, feed 0.2 mm/revolution, flan ID: DCMT 070202-HMP, supplier: Kolroy Inc.) was applied for surface machining. The average general roughness of the manufactured surface was Sa=3.2 micrometers, the geometrical average of deviations was Sq=4 micrometers. The average values of skewness and kurtosis parameters to characterize the distribution of points in the direction of the vertical axis were Ssk=0.739 and Sku = 2.72, respectively.

Afterwards the tribology test specimens produced were destroyed in a pin-on-plate arrangement in the first step, at 150mm length and 25 mm/s velocity, with a contact surface of 30mmx30mm, subject to 600 N normal force, using an abrasion cloth of 1200 fineness (type: CK721X, procurement: Fk-Technika Kft.) perpendicularly to microtopography orientation. The end of the process was defined at 10,800 mm wear route length by the total destruction of roughness valleys located in the waviness valleys produced during manufacturing. In the second half of the experiments, the force compressing the surfaces was changed between 200 N and 600 N by 100N steps; the wear route length was increased by 600 mm steps up to 4800 mm, and then by 1200 mm steps to 10,800 mm, subject to 25mm/s wear velocity.

The surface microtopography of test specimens was measured after each test using a Mahr stylus instrument for roughness measurement. A FRW750 instrument was applied for measurements, with a nose angle of 90°, and a rounding radius of 5 micrometers. Measurements were performed on a 1mmx1mm surface, with a 2 micrometer step in each direction. The results yielded were taken into consideration without filtering in the course of further evaluation (Fig. 4).

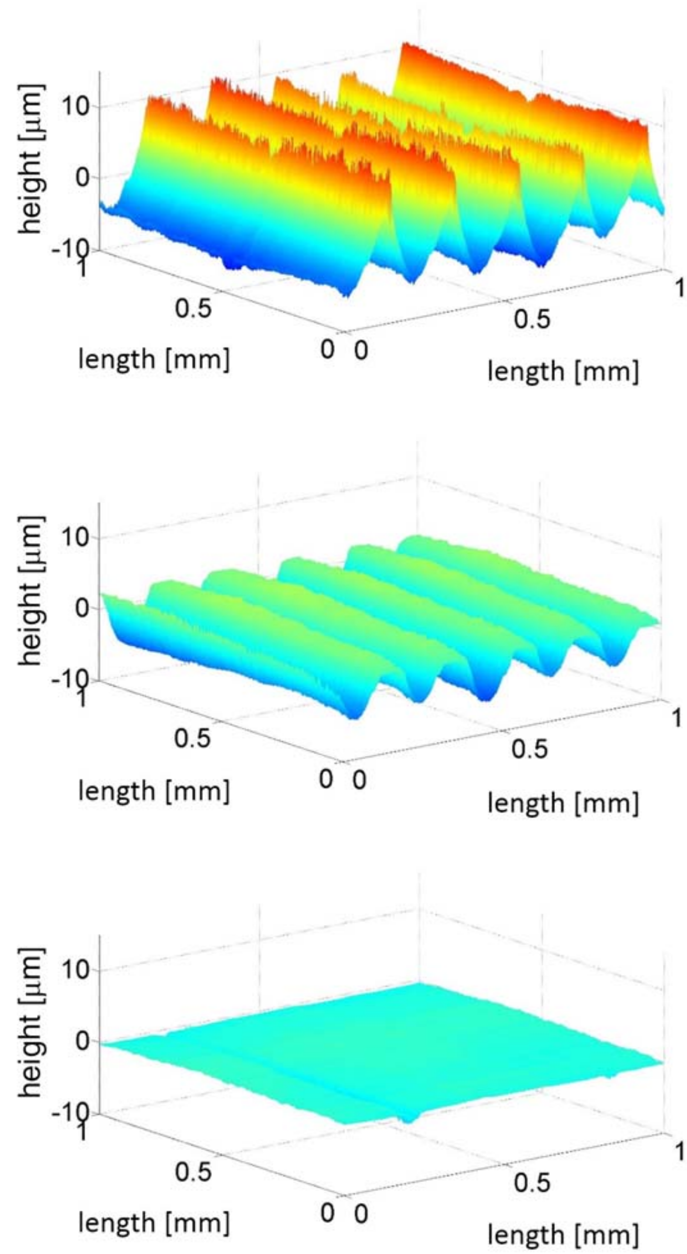



Fig 4. Surface microtopography in three different states: manufactured, abraded with a force of 200N along 4800 mm, abraded with a force of 600N along 10,800 mm

# 3. RESULTS

In this chapter results of the simulation model and the test plan was presented, and the roughness parameters modification was defined by logistic function.

### 3.1. Simulation model results

When using the simulation model, the microtopography was divided into 100 parts in the height direction where the volume of the material quantity removed was constant. Figure 5 shows changes in the parameters defined by the algorithm.

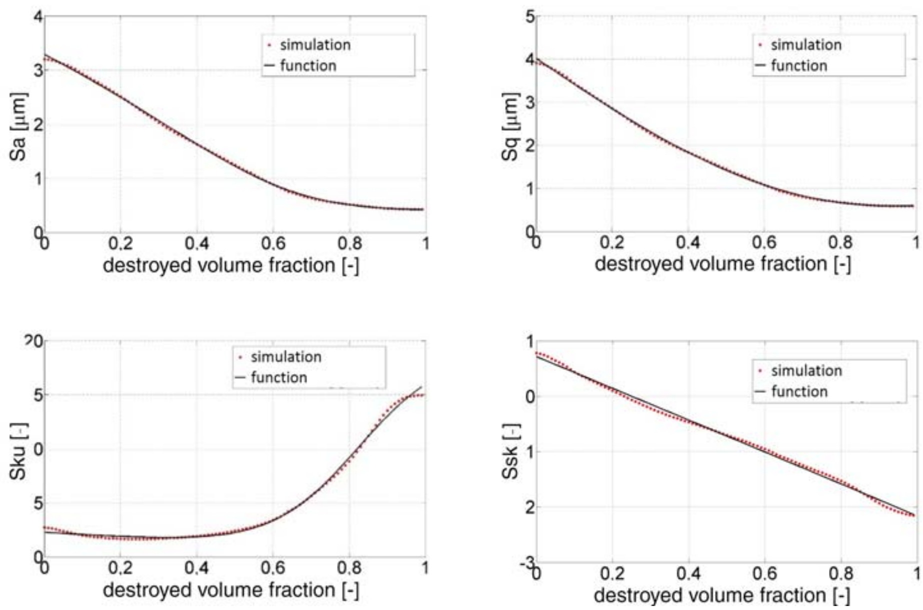



Fig. 5. Changes in parameters Sa, Sq, Sku, and Ssk in function of the volume portion destroyed

For the mathematical description of the results yielded, a modified logistic function (5) was used and Table 1 summarizes the results of functional approximations.

$$f = \frac{ax + b}{1 + e^{cx+d}} + g \tag{5}$$

Table 1.The coefficints of the logistic functions

| | a | b | c | d | g | $R^2$ |
|---|---|---|---|---|---|---|
| Sa [µm] | -3.271 | 2.954 | 5.827 | -3.273 | 0.444 | 0.9995 |
| Sq [µm] | -6.086 | 2.176 | 2.875 | -2.321 | 2.031 | 0.9995 |
| Sku [-] | -2.137 | -16.88 | 8.75 | -7.144 | 19.14 | 0.9973 |
| Ssk [-] | -6.58 | -1.204 | -0.011 | 0.2644 | 1.24 | 0.9962 |

### 3.2. Test plan results

A full factor test series was performed in order to validate results. Experiments were intended to answer the question whether the truncation algorithm represented a suitable approximation to the results yielded by model experiments. In order to compare results, the modified logistic function was extended into three dimensions in the following form:

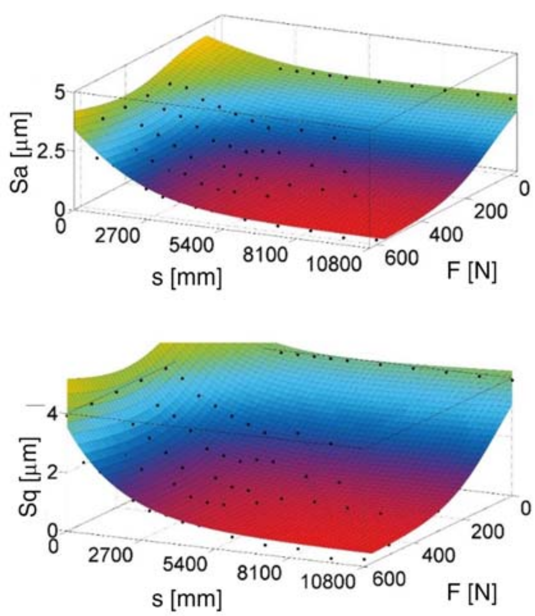
$$f(x,y) = \frac{(ax+b)}{1+e^{(cy+d)}} + \frac{(hy+k)}{1+e^{(lx+m)}} + n \tag{6}$$

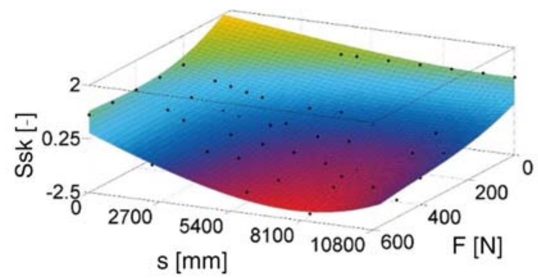
The equation form was used in accordance with equation (7) for function approximation in respect of force, course, and roughness parameters:

$$S = \frac{\left(\frac{a \cdot F}{1000} + b\right)}{1+e^{\left(\frac{c \cdot s}{1000}+d\right)}} + \frac{\left(\frac{h \cdot s}{1000} + k\right)}{1+e^{\left(\frac{l \cdot F}{1000}+m\right)}} + const \tag{7}$$

If the value of force (F) is substituted into the equation in [N], and course (s) in [mm], then the unit of measurement of roughness parameters depending on amplitude will be micrometers and statistical parameters will be dimensionless. The constant value of equation (8) defines the displacement in the direction of the vertical axis applied in function approximation, its value equals to the value of totally destroyed microtopography.

The function approximation of measurement results is shown in Figure 6 and the calculated coefficiens summarized in table 2.





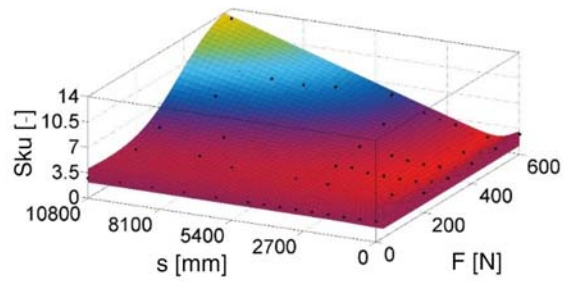




Fig. 6. Changes in parameters Sa, Sq, Sku, and Ssk in function of normal force and wear route length

Table 2. Logistic function coefficients specified from the test plan

| | a [μm/N] | b [μm] | c [1/mm] | d [-] | h [μm/mm] |
|---|---|---|---|---|---|
| Sa [μm] | 7,375 | 2,601 | 0,6106 | 0,3725 | 0,03795 |
| Sq [μm] | 72,5 | 31,81 | 0,5326 | 3,044 | 0,06937 |
| | a[1/N] | b [-] | c[1/mm] | d [-] | h [1/mm] |
| Ssk [-] | -19,42 | -3,657 | 0,3096 | -4,58 | -0,7837 |
| Sku [-] | -6,063 | -0,0491 | -3,14 | 1,418 | 1,286 |

| | k [μm] | l [1/N] | m [-] | const [μm] | $R^2$ |
|---|---|---|---|---|---|
| Sa [μm] | 2,875 | 10,02 | -1,516 | 0,4294 | 0,9397 |
| Sq [μm] | 3,524 | 10,01 | -1,224 | 0,5928 | 0,9465 |
| | k [-] | l [1/N] | m [-] | const [-] | $R^2$ |
| Ssk [-] | 27,58 | -2,853 | 1,359 | -0,715 | 0,852 |
| Sku [-] | 0,8471 | -10,8 | 4,791 | 2,7376 | 0,9398 |

During my work in the linear spectrum analysis was extended to three dimension that the profiles are which perpendicular to the feed rate had been examined in wavelength space. These transformed profile data described the microtopography spectrum. The result of this procedure can be see in Figure 7 in a case of machined surface.

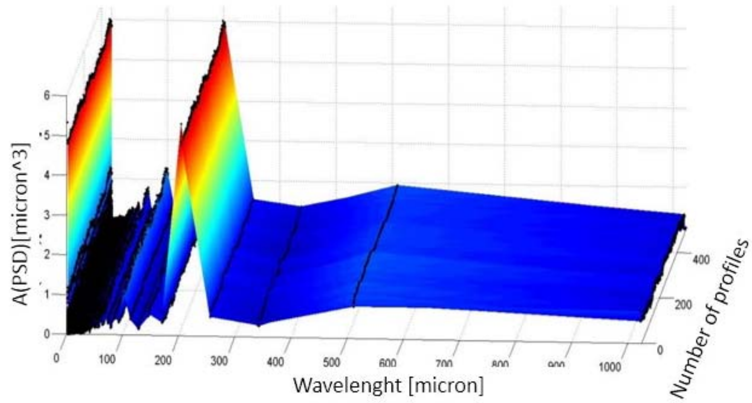



Fig. 7. The wavelength components of profiles

Figure 7 shows that the profiles have a dominant wavelength of 204 microns wavelength (the feed rate was 200 micrometres).

According to the profiles data content smaller wavelengths defines roughness the higher wavelengths defines  waviness characteristics. We observed from the graph that the smaller wavelengths have been defined more points. According to this the dominant wavelength and the smaller wavelength have been defined more specifically. The larger wavelengths cannot be specific and precise controls for Shannon sampling law. In our case, for example, that if you have a 800-micrometer-signal component, it defines with different wavelengths composition.

The modification of the amplitude defined by wavelength defined by feed rate and the coefficients of variation can be summarized in Figures 8 and 9..

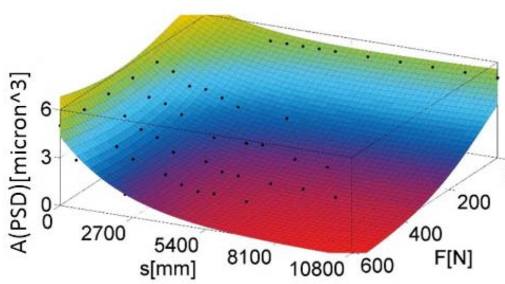



Fig. 8. The PSD amplitude in a function of distance and force

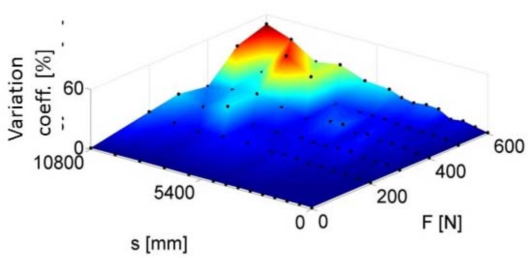



Fig. 8. The CV of the PSD amplitude in a function of distance and force

# 4. NEW SCIENTIFIC RESULTS

In this study the steel part running in stage abrasion wear process was characterised with the help of truncation algorithm and validated by design of experiment.

The new scientific results help engineers and scientist to optimise the surface microtopography and examine the abrasion process with the help of the roughness measuring system.

My new scientific result is:

1. *Developing a truncation algorithm*

   I developed a simulation model that allows to determine the modification of the microtopography in a case of any flat machined surface in abrasion condition in the initial stages of wear. The algorithm with the help of same size and resolution shaped and worn microtopography and the number of steps can link the disappeared topography (the truncation height) and the roughness parameters taking into account the influence abrasive scratches the peak zone is located used constant material removing of any steps.

2. *Defining the applicability of the profile and the microtopography measurement technique*

   For abrasion worn surface profile measurements and microtopography measurements proved that the abrasive grain used (600, 800 and 1200-grit sandpaper) and roughness measurement technology (profile or microtopography measurement) affect the coefficient of variation of describing the surface quality parameters value named Sa, Sq, Ssk, Sku.

   According to my measurements that Sa and Sq parameters have smaller variation coefficients as Ssk and Sku parameters, as well as the microtopography measurements describe with stronger correlation the wear process as a linear roughness measurement technology with the help of the examined parameters.

3. *Defining the connection of the normal force, the sliding distance and theroughness partameters*

   With the help of modified logistic function the amplitude dependent roughness parameters characterised in a function of normal force and the sliding distance, given measurement conditions (F = 0 N-600 N, S = 0 mm 10 800 mm, in case of dry friction 1200 grit abrasive cloth) in the initial stage of wear.

$$S=\frac{\left(\frac{a\cdot F}{1000}+b\right)}{1+e^{\left(\frac{c\cdot s}{1000}+d\right)}}+\frac{\left(\frac{h\cdot s}{1000}+k\right)}{1+e^{\left(\frac{l\cdot F}{1000}+m\right)}}+\text{const}\,.$$

   Full factorial design of experiments was determined and the coefficients calculated for Sa, Sq, Ssk, Sku roughness parameters.

4. *Defining the end of the initial stage*

   With the help of the truncation algorithm and the design of experiments was defined the prediction method of disappear of the original surface microtopography with the help of the Sku parameters in a case of constant normal force, velocity and abrasion process. This parameter value drastically changes when the abrasion scratches dominance increases and the peak zone starts to be flatted. These two process causes the modification of distortion of topography points of the topography sharply

5. *Evaluating of the design of experiment in the wavelength space*

   The feed rate defined wavelength amplitude numerically characterizes the dynamics of the abrasion process. The design of experiments defined abrasion path and the normal force describe that the feed rate specified waviness PSD amplitudes goes to zero and the coefficient of variation values increased in state of the end of the initial stage.

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# 5. CONCLUSION AND SUGGESTION

During my research an achievement of the multi-faceted description of the initial phase of the dry friction abrasive wear process made with the help of the algorithm and design of experiment. This stage of the wear defines complex physical processes, which examined only a certain portion of my research topic. The defined truncation algorithm and the test provides an opportunity to characterise the abrasion process running-in stage in a point of view roughness measurement.  During my work

In my research an algorithm had been defined which take into consideration abrasive scratches in the initial stage of wear. According to the algorithm I proved that the scratches highly influence in the test conditions. With the help of the algorithm the mostly used roughness parameters valueshave been calculated during the simulation process

The other area of my research is the applicability of surface roughness measurement techniques. Profile roughness measurements had been made in a case of non-orientated case and roughness, waviness parameters calculated. According to measurements I made a conclusion to the roughness and waviness are not defined clearly, and the shape of the profiles are depend of the type of the filter, so during my work non filtered data used to characterise the roughnees and vaviness profile modification together.  I used only polinamial filter to characterise a form error. In my work proved to the microtopography measurements characterise better the quality of the surface than the profile measurement.

During my research I examined a modification of the roughness parameters in a fiunction of the normal force and sliding path and found to the roughness parameters named average roughness (Sa), the geometric mean of the differences (Sq), the skewness (Ssk) and kurtosis (Sku) can be described by three dimensional logistic function. According to test and the algorithm determined that the Sku parameter surge increase predicts the destruction of microtopography.

Models which created in my research can be improve to different sliding path and normal force intervals when the abrasion scratches destruct only the peak zone.

The truncated algorithm and statistical functions allow to define the worn stage of the surface in the engineering practice.

# 6. SUMMARY

The initial stage of wear is significant for the tribological behavior of the components. The machining parameters defined microtopography changes continuously during the operational effects. These changes are determined by the behavior of the other components: for example, modify the real contact area, the heat transfer, friction and lubricant properties.

The purpose of my research was to characterize the running-in stage of wear by roughness measurement technology. In my research work I examined roughness (R) applicability to this topic. These parameters widely used to characterize the machined microtopography, but I found that the application of waviness (W) and roughness (R) profile data can be more useful for a description of the surface quality.

Further comparisons were performed profile and microtopography measurement test ina case of abrasive worn speciemen. I concluded to the value of variation coefficient of the reoughness parameters is depend on the size of the abrasive grain in a case of initial stage of wear. Test were performed using profile measurement and microtopography measurements and found that the measurement of microtopography smaller coefficient of variation is characterized by worn abrasive surface.

During my research is developed a truncated algorithm which considered the effect of the abrasive scratches in the peak zone. During the algorithm testing I found that the roughness of the scratches had significant impacts at the running-in stage. I made 100 step running in a case of oriented microtopography and abrasion worn microtopography. The arithmetical mean height (Sa), the root mean square height (Sq), the skewness (Ssk) and kurtosis (Sku) parameters was calculated. In the evaluation of results I determined the relation between the disappeared volume and the roughness parameters by logistic function. The model can be adapted to other machined microtopography description in a case of abrasion process.

Furthermore, full factorial DOE was applied. The DOE represented the roughness parameters in wide range of force and wear path in a case of abrasion and dry friction. The experiments were evaluated by the three dimensional extension of logistic function. According to these function I proved that the modification of parameter named Sku can predict the destruction of the microtopography. The experiments transformed to wavelength space can be characterize the changes of the dominated wavelength amplitude modification and its connection to the peek zone destruction.

## 7. MOST IMPORTANT PUBLICATIONS RELATED TO THE THESIS

*Referred articles in foreign languages:*


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2. **Barányi I.,** Keresztes R., Szakál Z., Kalácska G. (2016), Prediction of surface roughness parameters by new experimentally validated modelling algorithm under abrasive condition, Acta Polytechnica Hungarica, Vol. 13, Issue 7, pp. 197-208, ISSN 1785-8860
3. **Barányi I.,** Czifra Á., Kalácska G. (2011), Height-independent topographic parameters of worn surfaces, Sustainable Construction and Design, Vol. 2, Issue 1, pp. 35-40, ISSN: 2032-7471
4. **Barányi I.,** Kalácska G., Czifra Á. (2011), Three dimensional Fourier analysis of the surface microtopography, Mechanical Engineering Letters, Vol. 5, pp. 161-165, HU ISSN 2060-3789
5. **István Barányi** (2013), Influence of abrasion wear process on amplitude roghness parameters, Mechanical Engineering Letters, Vol. 9, pp. 16-20, HU ISSN 2060-3789
6. **Barányi I.,** Kalácska G., P. De Baets (2013), Characterisaton of abrasive worn surfaces by surface microtopography parameters, Sustainable Construction and Design, Vol. 4, Issue 2, pp. 1-4, ISSN: 2032-7471, http://ojs.ugent.be/SCAD/article/view/1036/1052


*Referred articles in Hungarian:*


1. **Barányi I.,** Czifra Á. (2009), Különböző megmunkálású felületek vizsgálata amplitúdó sűrűség spektrum (PSD) analízissel, GÉP, 60. évf., 10-11 sz., 7-10. o.
2. **Barányi I.,** Czifra Á., Kalácska G. (2010), Felületi mikrotopográfiák fraktál dimenziójának meghatározása, GÉP, 61. évf., 9-10 sz., 7-10. o.
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