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POWER SPECTRAL DENSITY (PSD) ANALYSIS OF MACHINED SURFACES

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In the first half of the 90s, computers of adequate speed of operation and processing softwares became increasingly available, made it possible to realize 3D surface characterisation. In the literature different directives can be found none of them has become widely used. Beside the extension of 2D parameter based technique to 3D many other methods have been developed. One is the power spectral density (PSD) technique when "global" surface characterisation is carried out using complex mathematical tools.

Nowadays one of the most important tasks in tribology to design the surfaces optimised to the operation. In the present study topographical measurements and PSD characterizations were performed to study the engineering surfaces produced by turning and to analyse the effectiveness of 2D and 3D PSD.

Keywords: power spectral density, topography, fractal dimension

Introduction

Efficient research in the course of the past decades has provided experts involved in surface microtopography research with a number of tools and methods to design an operationally optimized surface. At the same time, this knowledge is utilized only to a small degree in the analysis and control of tribological processes. Characteristically, designers continue to content themselves by requiring few roughness parameters [1].

In the first half of the 90s a lot of surface characterisation method has been developed. One is the power spectral density (PSD) technique when "global" surface characterisation is carried out using complex mathematical tools. PSD provides full length scale analysis, which takes into consideration not only the dominant topographic elements but also the submicro features, in contrast with traditionally surface characterisation methods. The fractal dimension derived from PSD topography seems to be an efficient tool for characterization.

In the present study topographical measurements and PSD characterizations were performed to study the orientated engineering surface two and three dimensional fractal analysis. In my experience, these methods are associated with in point of view of fractal dimension.

Mathematical background of characterisation

To characterize the measured topographies an algorithm was developed in cooperation with Department of Machine and Industrial Product Design, Budapest University of Technology and Economics and interpreted as PSD analysis software. The theoretical base of 3D PSD analysis was [2] and [5]. Discrete Fourier transformation (DFT) of 3D topography can be written as follows:

$$F(q_x, q_y) = \Delta y \cdot \Delta x \sum_{d=1}^{N} \sum_{c=1}^{M} z(x_c, y_d) e^{-i2\pi(x_c q_x + y_d q_y)} \qquad (1)$$

where: q_x – frequencies in x direction,
q_y – frequencies in y direction,
$z(x_c, y_d)$ – height coordinate located in x_c, y_d,
M – number of points in profile,
N – number of profiles,
Δx – sampling distance in x direction,
Δy – sampling distance in y direction.

DFT gives complex results:

$$F(q_x, q_y) = \mathrm{Re}(F(q_x, q_y)) + i \cdot \mathrm{Im}(F(q_x, q_y)) \qquad (2)$$

The PSD "amplitude" is calculated *(Fig. 1)*:

$$A_{PSD} = \frac{\mathrm{Re}^2 F + \mathrm{Im}^2 F}{MN\Delta x \Delta y} \qquad (3)$$

where: A_{PSD} – PSD amplitude,
Re F – real part of the Fourier transformation,
Im F – imaginary part of the Fourier transformation.

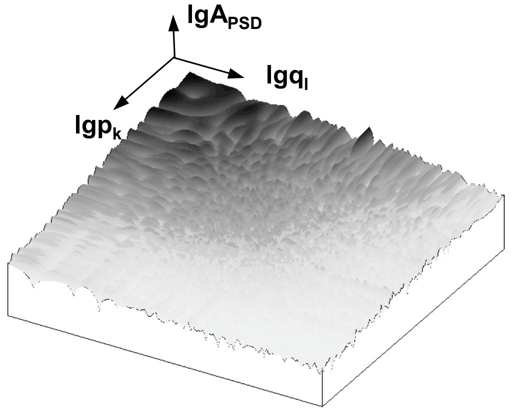

Figure 1: PSD Surface

PSD topography can be reduced to PSD curve using (4). It means 2D representation, which can be easy handled, but contains 3D information about topography *(Fig. 2)*.

$$q = \sqrt{q_x^2 + q_y^2} \quad (4)$$

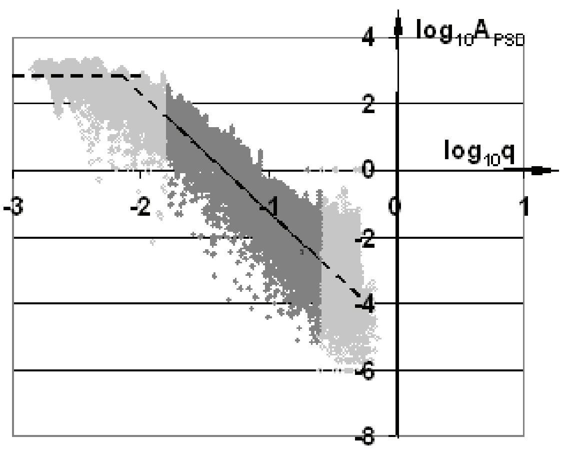

Figure 2: PSD curve from the reduction of the PSD surface

There are two possibilities of showing results. One is to represent the amplitude of PSD in the function of wavelength. The other prevalent method is logarithmic scale frequency-PSD amplitude visualization. The practical gain of the first method is that dominant wavelength components appear as a maximum point of the PSD curve. In the second method the height frequency range of the curve can be approximated by a line. The slope of the line is in correlation with the fractal dimension of surface. In the latter case, wavelengths smaller than the highest dominant wavelength play a considerable role. PSD amplitude becomes constant – the self-affinity character of the surface disappears – in a lower wavelength range. The slope of fitted line (s) to PSD curve has correlation with fractal dimension of surface according to (5).

$$Df = 4 + \frac{s}{2} \quad (5)$$

where: *Df* – fractal dimension.

PSD analysis of the theoretical surface

In this part I solve the fractal dimension of the theoretical surface. This analysis gives a chance to investigate the surface PSD profondly. In this part I generate a topography which is constans in every direction. The PSD surface and PSD curve of this surface summarised in *Fig. 3* and *Fig. 4*.

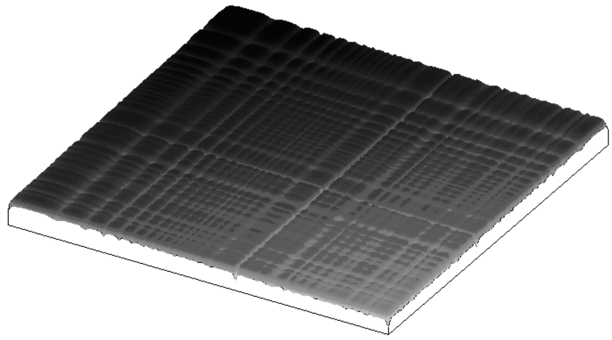

Figure 3: Theoretical surface PSD analysis

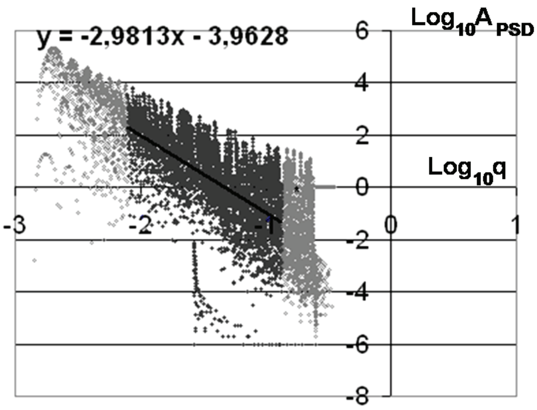

Figure 4: Approximating straight line

The calculated fractal dimension from the slope of the straight line is *Df* = 2,51. We can see in Fig. 3, the applied program use calculating in logarithmical scale.

In Fig. 4 felharmoincal points are farther position of the straight line.

Two and three dimensional PSD analysis of the turned surfaces

The turned surfaces have two orientation: one is perpendicular, and the other is paralell with the machining direction. The profiles of these directions are different (*Fig. 5* and *6*). In this part I choosed a surface, which average surface roughness war Sa = 3,02 μm. In this part of investigation was the fractal dimension in direction of paralell and perpendicular direction with machining direction.

Fig. 5 shows the profile with characteristic wavelenghts. *Fig. 7* representes this profile main wavelenghts. Parallel in the machining direction (Fig. 6) can't find characteristic wavelenghts *(Fig. 8)*.

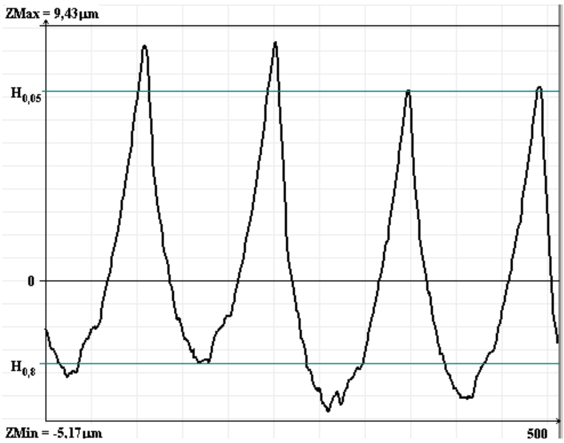

Figure 5: profile in perpendicular with machining direction

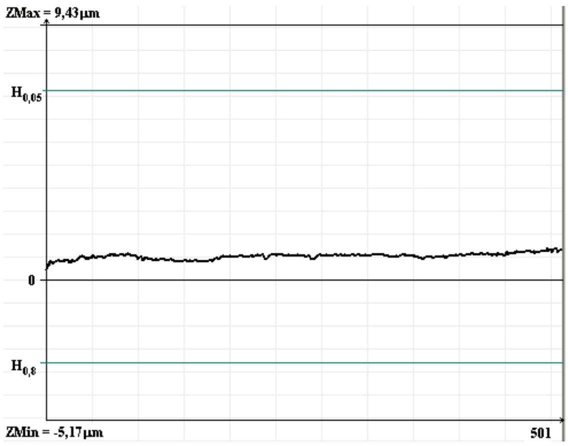

Figure 6: Profile in parallel in the machining direction

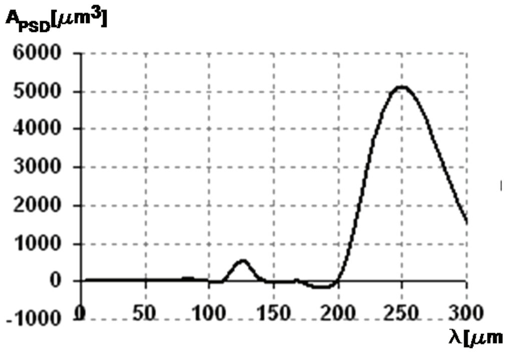

Figure 7: Profile 2D PSD analisys in machining direction

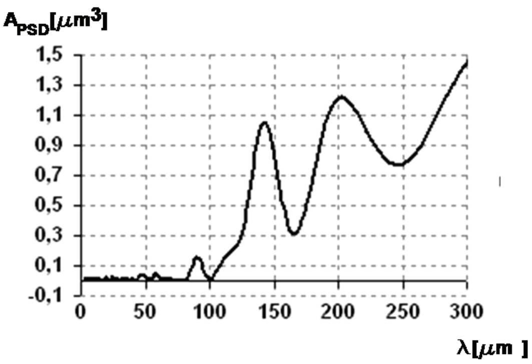

Figure 8: Profile 2D PSD analisys in perpendicular with machining direction

The calculated fractal dimension of the profile is $Df = 1.36$ in machining direction and the turned topography fractal dimension is $Df = 2.33$.

In this case the Persson equation associate the profile and the surface fractal dimension. The affection of small PSD amplitudes (in parallel direction of the machinining direction) isn't considerable in the calculation of 3D fractal dimension (the 2D farctal dimension is in 1 and 2, and the 3D fractal dimension is 2 and 3). The 3D fractal dimension is one more than 2D fractal dimension.

Analisation of turned surface with various roughness

In this part of investigation I generated profiles with various average roughness from the original profile (Fig. 5). The profiles can be solved with constants multiplication. This generation algorythm can be warranted to waves are same in the profiles and the average roughness is more or less than the original profile's.

Table 1 summarizes the average roughness, the two dimensional and three dimensional fractal dimension and the vertical axis intersection of the generated profile. *Fig. 9* shows the modification of the vertixal axis intersection.

Based on these results it can be supposed that fractal dimension didn't modify, when the profile is increased in vertical direction. This increasing modify the PSD amplitude and offset the Persson line up.

Table 1: characterestic data of the profile

	2D analysis		3D analysis	
Ra [µm]	intersect. with vertical axis	*Df*	intersect. with vertical axis	*Df*
0.6	-7.1066	1.36	-7.0378	2.33
0.75	-6.9127	1.36	-6.8631	2.33
1.51	-6.3107	1.36	-6.2931	2.33
3.02	-5.7086	1.36	-5.7114	2.33
6.03	-5.1066	1.36	-5.1487	2.33
9.05	-4.7544	1.36	-4.8218	2.33
12.06	-4.5045	1.36	-4.5895	2.33
15.08	-4.3107	1.36	-4.4379	2.33

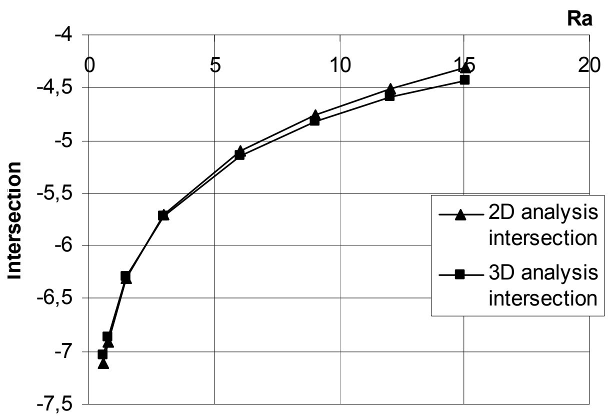

Figure 9: the modification of the vertixal axis intersection

Conclusion

The turned surfaces farctal dimension is different in dirrection of perpendicular and parrellel direction. The characteristic direction is parallel with the machining direction. The 3D fractal dimension is one more than the parallel profile fractal dimension. The profiles fractal dimension isn't change, when the profile is blown up or reduced. The Persson line intersection with the vertical axis is modify in blown up or reduced profile.

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