MICRO AND NANO SCALE STATISTICAL PROPERTIES OF ROUGH SURFACES OF SIGNIFICANCE IN THEIR FRICTION

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1 Introduction

The paper is devoted to statistical analysis of rough surfaces and extraction of parameters of significance for modelling of friction between the surfaces. It is known that modern experimental techniques, e.g., techniques based on atomic-force microscopy (AFM) allow the researchers to describe the surface topography up to atomic scale resolution. However, to predict any tribological process one has to understand which parameters of the rough surfaces are the governing parameters for the process under consideration and to be able to predict the changes in the process behaviour when the parameters are varied. Nowadays more than 30 parameters and functions are used in order to characterize the complex structures of rough surfaces. In particular, these parameters include (i) height (amplitude) parameters, e.g. the maximum height of the profile; (ii) horizontal parameters, e.g. the number of intersections of the profile with the mean line; (iii) parameters related to the shape of protuberances, e.g. the root mean square (rms) slope and the rms curvature of the profile; and (iv) parameters associated with spatial extend and amplitude of the roughness, like the high spot count [1, 2]. Whitehouse and Archard [3] suggested to study the surface roughness using the auto-correlation function and its Fourier transform, the power spectral density. The fractal approaches to description of the surface roughness are caused by experimental observations that graphs of the spectral density of the surface topography have often the power-law character [2,4]. However, it was shown that neither fractal dimension nor the power spectral density can be the single parameter or function that may characterise tribological properties of rough surfaces [2,5] and hence the some modern models of contact between rough surfaces that are based solely on their spectral density or fractal dimension, are of little use for practical applications. Hence, new statistical approaches to characterisation of rough surfaces that are connected to surface features related to physical mechanisms of friction have to be explored. It is proposed to split the scales of consideration of the surfaces into nano and micro-scales due to the difference of physical mechanisms acting at these scales. Using several modern statistical approaches including the sliding window techniques and the Kolmogorov-Smirnov statistics for two samples, simpler profiles with equivalent roughness in terms of the height distribution are constructed. The simple profiles obtained earlier can be further simplified by using the sorting techniques. We can say that the mechanical and tribological properties of the simpler profile and the original one are the same.

2 Multiscale hierarchical models of rough surfaces

Friction is defined as the force resisting the relative motion of bodies in contact. It has been proposed recently to model friction between rough surfaces using a nominally flat slider represented as a multiscale, hierarchical system of connected deformable components [6,7]. The model takes into account not only the hierarchical multilevel structure of roughness but also the adhesive interactions, the deformation of asperities, transfer the deformations between levels of the hierarchical structure and the vertical degree of freedom of the asperities. In addition, the model takes into account the Polonsky-Keer effect, i.e. the nano-scale asperities do not have plastic deformations even under very high pressure. It is assumed that the nano-scale asperities are responsible for the adhesive interactions between surfaces while the micro-scale asperities are the main cause for interlocking component of friction. The nano-scale asperities have several levels that reflect different mechanisms of adhesive/cohesive interactions between asperities that in turn depend on the environmental conditions of the surfaces. The modern techniques of measurements allow the researcher to gain information about both nano and micro-scale asperities. The experimental data on roughness at micro and nano-scales are obtained by a profilometer and an AFM respectively.

3 Simpler profiles with equivalent roughness

We consider two datasets with measurements of roughness for a nominally flat cooper surface at nano and micro-scales respectively. The histograms of heights for roughness data at these scales obtained by AFM and profilometer stylus respectively, are presented in Figures 1 and 2. One can see that both distributions of heights are not well fitted by the normal distributions.

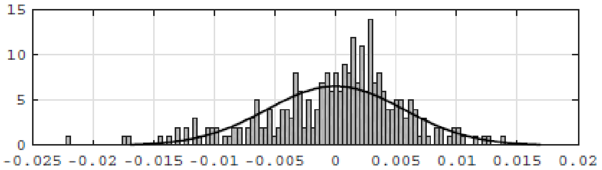

Figure 1: The histogram of heights for nano-scale data for the segment [0; 40] μm with the fitted normal distribution.

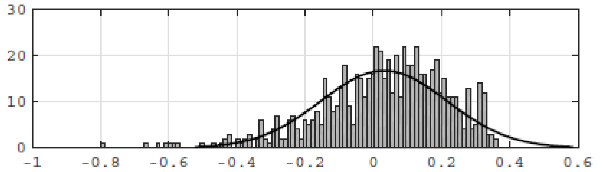

Figure 2: The histogram of heights for micro-scale data for the segment [0; 1000] μm with the fitted normal distribution.

If one superimposes the series obtained by AFM (which covers [0; 40] μm) and by a profilometer (which is truncated to [0; 40] μm) then he can see that the amplitude of the AFM series is very small and it gives a tiny contribution to the sum. The AFM series does not describe the surface of the sample except segments whose length is smaller than 1 μm.

Consider the series of heights with K = 1000 points, which is obtained by a profilometer and consider a problem of constructing another series that has the same height distribution and a simpler structure, i.e. we will look for a series which is obtained by a replication of some pattern. To find the pattern, we will slide a window of length $L < K$ along the initial series and compute the Kolmogorov-Smirnov statistic for two samples [8]: initial and another extracted by the sliding window.

The new profile is equivalent to the original one in terms of the height distribution. Due to the assumption that the profile is homogeneous for different parts of the full measurement interval, we expect that asperities for the simpler profile will be similar to asperities for the original profile.

The above simple profile can be simplified further by sorting. This profile has the same height distribution and a similar volume function (the Abbott bearing curve) as the original profile. The same procedure may be applied to nano-scale roughness data obtained by AFM (see Fig. 3).

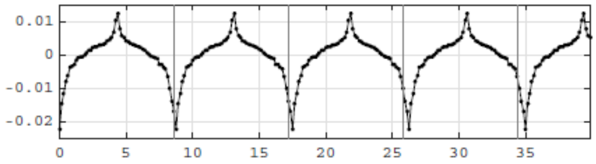

Figure 3: The very simple profile with the same height distribution and a similar volume function as for the original nano-scale data (units are in μm).

We note that the lengths of these very simple profiles are smaller than the lengths of the original profiles. These simple profiles may have a slightly different volume function because the proximity was not controlled for the choice of a best pattern.

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