Notes regarding the roughness filtering effects on wear predictions

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Abstract: *Roughness measurements have been part of engineering for many decades. Direct contact scanning, white light and laser devices have been routinely used to provide 2D of 3D roughness data files and various roughness parameters. This has also enabled researchers to develop more and more advanced wear models, many of which incorporate contact mechanics; roughness filtering have also been systematically used to select the features of interest and although standards exists that regulate application of roughness filters for geometrical product specification, the impact of filtration upon wear is still subject of open research. This paper discusses some aspects regarding the digital filtering as applied to roughness data and the effect of roughness filtering on wear.*

Key Words: *Roughness measurements, Roughness filtering, Wear prediction*

1. INTRODUCTION

Roughness measurements have been part of engineering for many decades. Direct contact scanning, white light and laser devices have been routinely used to provide 2D of 3D roughness data files and various roughness parameters.

The stylus measurements contain systematic errors due to the effects of the size of the tip (equivalent to a low pass filter), load, stylus dynamic response and stylus skid so differences exists between the stylus measurements and other types of measurements Ref. [1].

Filtration effects on roughness data have been discussed for many decades Ref. [2]. Standards describing the use of roughness filters are currently included within the ISO 14638:2015 Geometrical Product Specification and Verification system, however, filtration of roughness data have continued to be a topic of open research, Ref. [3].

Wear modeling has also been addressed for many decades; the 1995 review paper of Meng and Ludema, Ref. [4] specify a number of 5466 papers dealing with wear, that discussed 182 wear equations. The more recent review paper of Zhang, Goltsberg and Etsion, Ref. [5] discusses 82 papers and concludes that although the wear rate of metals have had long been expected to be predicted based on first principles and fundamental material properties, to date, such a satisfying prediction model has not been reached and many analyses are based on the famous empirical Archard wear equation, Ref.[6]. Frerot, Aghababaei and Molinari Ref.[7] proposed a mechanistic based algorithm for the empirical wear coefficient, however, a widely accepted physics based wear algorithm is not available yet. Many experimental and theoretical studies have been devoted to the impact of surface parameters on wear, however, the impact of the roughness filtering on wear predictions is still insufficiently addressed. This paper discusses some aspects regarding the digital filtering as applied to roughness data and the effect of roughness filtering on wear predictions. The present report is not meant to be a thoroughgoing analysis, but an illustration of these effects.

2. ASPECTS RELATED TO ROUGHNESS FILTERING AND CALCULATING OF THE ROUGHNESS PARAMETERS

Data generated by the roughness meters must first be “cleaned” of erroneous measurements and next the tilt and curvatures must be eliminated as well. Once this is done, the statistical parameters that characterize roughness can be calculated using well established equations; many roughness parameters have been proposed and are included in textbooks and standards, however, recent research emphasize that wear is significantly influenced by roughness magnitude, skewness, *Rsk*, and kurtoisis, *Rku*, Ref. [7-8], consequently we will only address the calculations of these three parameters, that is,

$$\boldsymbol{R_q} = \sqrt{\frac{\sum_1^N (\boldsymbol{z_i} - \bar{\boldsymbol{z}})^2}{\boldsymbol{N}}}, \boldsymbol{Rsk} = \frac{\frac{1}{N}\sum(\boldsymbol{z_i} - \bar{\boldsymbol{z}})^3}{\left[\frac{1}{N}\sum(\boldsymbol{z_i} - \bar{\boldsymbol{z}})^2\right]^{3/2}}, \boldsymbol{Rku} = \frac{\frac{1}{N}\sum(\boldsymbol{z_i} - \bar{\boldsymbol{z}})^4}{\left[\frac{1}{N}\sum(\boldsymbol{z_i} - \bar{\boldsymbol{z}})^2\right]^{2}} \tag{1}$$

which, when the mean becomes zero due to tilt and curvature elimination, yield

$$R_q = \sqrt{\frac{\sum_1^N z_i^2}{N}}, Rsk = \frac{\frac{1}{N}\sum z_i^3}{R_q^3}, Rku = \frac{\frac{1}{N}\sum z_i^4}{R_q^4} \tag{2}$$

Various filtering methods have been utilized, Ref. [1-3], however, this paper will adopt a FFT filtering as it provides a clearer representation of the roughness frequencies within the data set, both before and after the filter is applied, thus allowing for a better description of the filtering upon the wear data.

FFT filtering is described in most signal processing textbook, however, the main elements are provided below (for a better readability of this paper), in the manner in which they were presented in Ref. [9]. For a set of values, equally spaced at a distance Δ, the coefficients of the Fourier transform are, for even N,

$$\begin{aligned} C_{2n-2} &= \sum_{i=1}^{N} z_i cos\left[\frac{2\pi(n-1)}{N}(i-1)\right], n = 2,3,\cdots,\left(\frac{N}{2}+1\right) \\ C_{2n-1} &= -\sum_{i=1}^{N} z_i sin\left[\frac{2\pi(n-1)}{N}(i-1)\right], n = 2,3,\cdots,\frac{N}{2} \\ C_1 &= \sum_{i=1}^{N} z_i \end{aligned} \tag{3}$$

while if N is odd, the coefficients are defined as above, for n from 2 to $(N + 1)/2$.
The original set of values $(z_i,\ \ i = 1,2,\ldots N)$ can be reconstructed as

$$z_i = \frac{1}{N}\left[C_1 + 2\sum_{n=2}^{\frac{N+1}{2}} C_{2n-2}\,cos\,\frac{2\pi(n-1)(i-1)}{N} - 2\sum_{n=2}^{\frac{N+1}{2}} C_{2n-1}\,sin\,\frac{2\pi(n-1)(i-1)}{N}\right] \tag{4}$$

and within this paper, the FFT filtering was implemented by nulling the coefficients that correspond to the desired spatial frequencies, respectively, wavelengths, i.e.

$$\nu_n = \frac{n-1}{T} = \frac{n-1}{N\Delta}, \lambda_n = \frac{T}{n-1} = \frac{N\Delta}{n-1} \tag{5}$$

where $T = N\Delta$ is the spatial period of the initial series of data, i.e., it is assumed that $z(0) = z(0 + N\Delta)$.

The lateral resolution of the measured data set analyzed herein (obtained as a 2D cut from a 3D measurement of a ground surface) is 1 micron, (sampling rate 1000 points/mm), so no wavelength over 2 microns can be detected and the representation of the frequencies in the signal is not very accurate if wavelength is below 6-7 microns, representing about 150 oscillations/mm.

Consequenly, low pass FFT filteres were applied with cut-off frequencies between 450 to 50 oscillations/mm, and the results are shown in Figures 1-

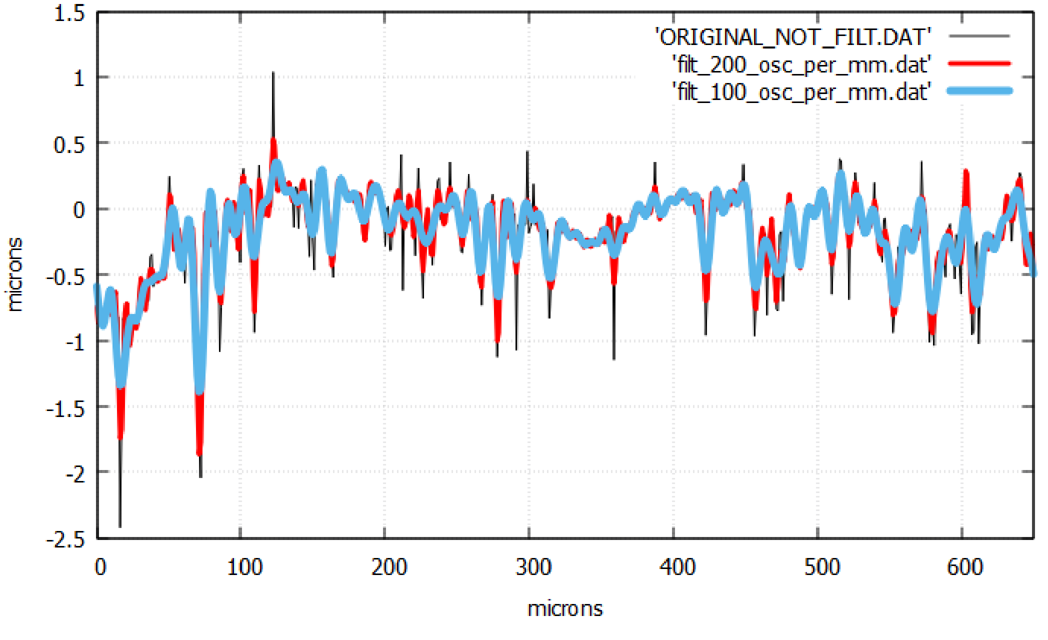

Fig. 1 – Filtered and non filtered roughness profile

The statistical data confirm a “valleys dominated profile”, *Rsk*≈-1.5 and very sharp peaks, with *Rku* ranging between 5 and 9, function of the applied cut-off frequency. Changes in roughness for the 50 oscillations/mm filter bring changes of about 20% in magnitude, 30% in skewness and 50% in kurtoisis, however, the changes generated by the 300 oscillations/mm filter are, on the average, about 10% for all these parameters.

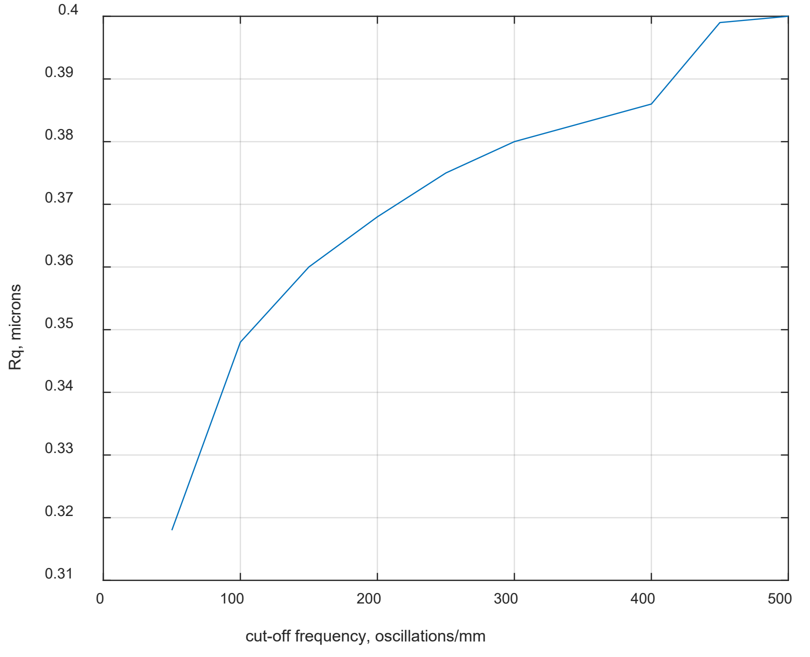

Fig. 2 – Roughness magnitude versus the cut-off frequency of the low pass FFT filter

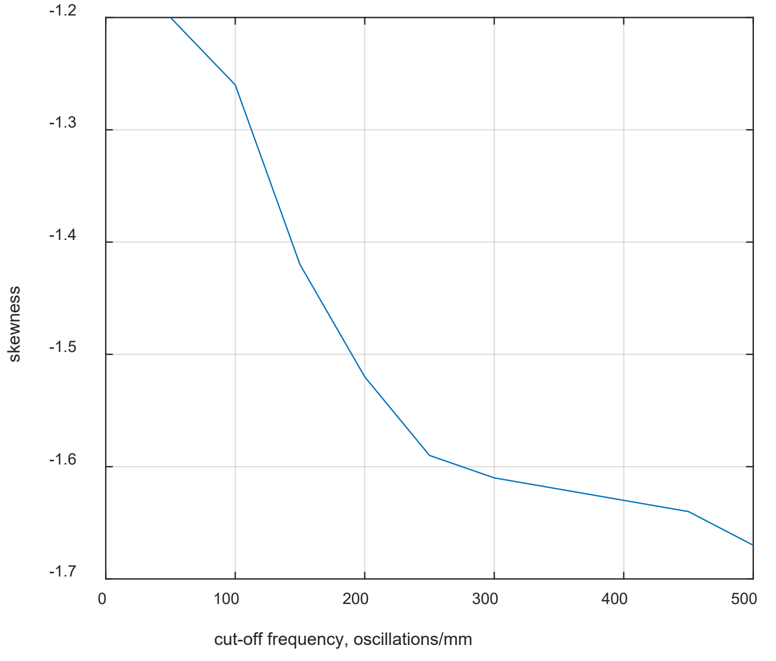

Fig. 3 – *Rsk* versus the cut-off frequency of the low pass FFT filter

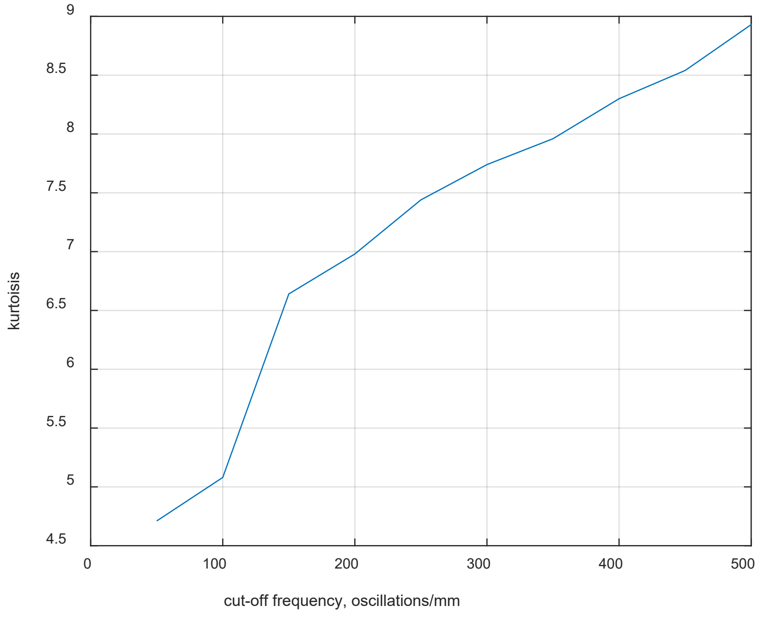

Fig. 4 – *Rku* versus the cut-off frequency of the low pass FFT filter

Changes in the surface parameters trigger changes of the wear predictions. The impact of the roughness filtration upon the wear data was estimated using the results of Ghosh and Sadeghi, Ref.[9]. The result, shown in Fig. [5], shows a roughly 38% wear reduction for the surface filtered at 50 oscillations/mm, however, the changes generated by the 300 oscillations/mm filter are about 12%.

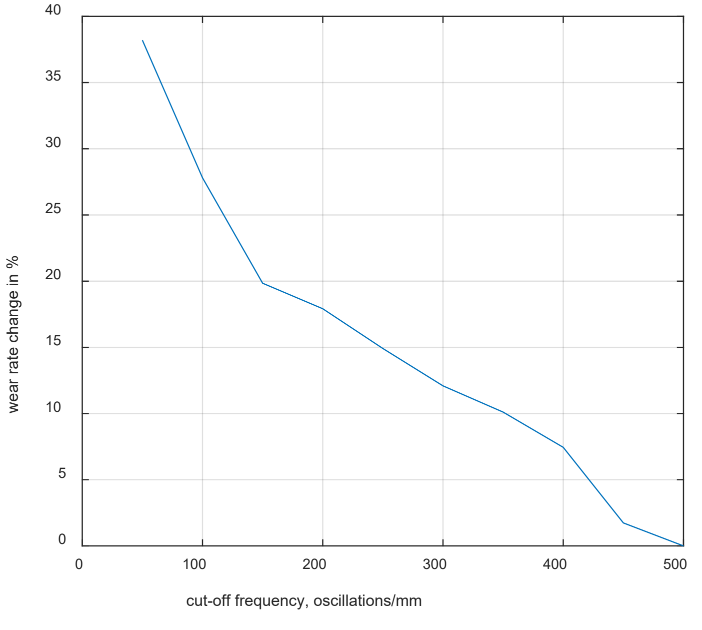

Fig. 5 – Wear rate reduction versus the cut-off frequency of the low pass FFT filter

3. CONCLUSIONS

A comprehensive analysis of the roughness filtering effects on wear predictions exceeds the limits of a journal paper. This paper addressed the impact of the low pas FFT filtering upon the roughness data of a ground surface measured at 1 micron lateral resolution. Changes in roughness for the 50 oscillations/mm filter bring changes of about 20% in magnitude, 30% in skewness, 50% in kurtoisis, and 40% in wear rate, however, the changes generated by the 300 oscillations/mm filter are, on the average, about 10-12% for all these parameters.

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