

OPEN ACCESS

Wavelet theory and belt finishing process, influence of wavelet shape on the surface roughness parameter values

To cite this article: Z khawaja *et al* 2011 *J. Phys.: Conf. Ser.* **311** 012013

View the [article online](#) for updates and enhancements.

You may also like

- [Development of mathematical model for material removal and surface roughness in electrolytic magnetic abrasive finishing process](#)
Nitesh Pandey, Rajnish Singh, Piyush Pant *et al.*
- [A Review on Experimental Investigation of Magnetic Abrasive Finishing process](#)
K Anjaneyulu and G Venkatesh
- [Study on the Motion Characteristics of Abrasive Media in Vibratory Finishing](#)
Wenwu Liu, Shuwen Wang, Qifeng Jiang *et al.*



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Wavelet theory and belt finishing process, influence of wavelet shape on the surface roughness parameter values

Z khawaja^{1*}, G Guillemot², P.-E Mazeran¹, M El Mansori³, M Bigerelle¹

1 Laboratoire Roberval, UMR 6253, UTC/CNRS, Centre de Recherche de Royallieu, 60205 Compiègne, France

2 Laboratoire Mécanique de Lille, UMR CNRS 8107, Equipe Freinage Contact Surface, Arts et Métiers Paris Tech, 8 Bd Louis XIV, 59046 Lille Cedex, France.

3 Laboratoire de Mécanique et Procédés de Fabrication (LMPF-JE2381), Arts et Métiers Paris Tech, Rue Saint Dominique, BP 508, 51006, Châlons en Champagne, France

Zahra.khawaja@utc.fr

Abstract. This article presents a multi-scale theory based on wavelet decomposition to characterize the evolution of roughness in relation with a finishing process or an observed surface property. To verify this approach in production conditions, analyses were developed for the finishing process of the hardened steel by abrasive belts. These conditions are described by seven parameters considered in the Tagushi experimental design. The main objective of this work is to identify the most relevant roughness parameter and characteristic length allowing to assess the influence of finishing process, and to test the relevance of the measurement scale. Results show that wavelet approach allows finding this scale.

1. Introduction

Precision tooling by turning and rectification of functional surfaces of mechanical parts, i.e. obtaining flawless parts both geometrical and structural, requires a considerable technical and economical effort. Some operations are completed by a finishing process such as the belt grinding process which is easier and less expensive than others finishing processes.

The difficulty is the incomplete knowledge of both the mechanisms and the characteristics of this process. Some authors analyzed the relations between the conditions of this process and the roughness of the surfaces obtained by experimental approaches [1, 2].

2. Experimental study

This process consists in applying an abrasive oscillating belt, of low thickness, on a rotating manufactured specimen. To assure the reproducibility of the process, five bearings, having a diameter of 54.78 mm and a width of 30 mm, are tooled for each group of test conditions of the experimental design. The width of the belt is 20 mm. Tagushi's experimental design is used to study the effects of the process conditions on the resulting roughness. The experiment was conducted using 16 work specimens that were turned and rectified. All samples are then manufactured with the same lubrication condition corresponding to 'Cut Max H05'. We retain 7 process parameters that are Belt feed (50 and 100 mm/mn), contact pressure (1 and 3 bars), Axial oscillation frequency (1.6 and 10 Hz), Contact

wheel stiffness (hard and soft), Cycles times (3 and 9 s), Belt Grit Size (9 and 40 μm) and finally Work piece rotation speed (100 and 500 rpm) [3].

This experimental design is built in a way to consider the contact wheel hardness versus the contact pressure, the contact wheel hardness versus the belt grit size, and the belt grit size versus the contact pressure. Roughness measurements are performed for each specimen. Thus, 30 roughness profiles were recorded from the tooled surfaces by a KLA-TENCORTM P-10 profilometer with a 2 μm tip radius. The scanning and the sampling lengths are respectively 8 mm and 0.1 μm .

3. Wavelets transform

Wavelet analysis is a mathematical tool recently developed for the signal treatment [4]. The main idea behind this analysis is using the wavelet functions satisfying certain mathematical requirements to analyze signals [5]. This approach uses windows with short width for the high frequencies and windows with large width for the low frequencies. Thus a multi-scale spatial analysis is developed.

The procedure of wavelet analysis begins by choosing a prototype wavelet function, called mother wavelet Ψ , to produce the other functions of different windows. This basic function will be translated and dilated to cover the plan time-frequency and analyze the signal.

By introducing the factors of translation, b , and of scale, a , we obtain the wavelet girl, $\Psi_{b,a}$:

$$\Psi_{b,a}(X) = \frac{1}{\sqrt{a}} \Psi\left(\frac{X-b}{a}\right) \quad (1)$$

So due to its properties of dilation-contraction and translation, the wavelet transform (WT) is characterized in the space-scale plane by a window of variable width. This width decreases when we focus on the structures of small scale (high frequency) or increases when we are interested in the large-scale behaviour (low frequency) [6].

Wavelet transforms are broadly divided into three classes: continuous, discrete and multiresolution-based. In our implementation the discrete wavelet transform (DWT) is used. This wavelet transforms defined by the following equation:

$$W_{i,j}(X) = 2^{j/2} \Psi(2^j X - i) \quad (2)$$

Where i and j are integers and $W_{i,j}(X)$ is the wavelet coefficient calculated in the scale j and at the position i . The DWT is based on a filtering algorithm developed by S. Mallat [7] in 1989. He considered the wavelet analysis as a decomposition of the profile by a cascade of filters, associating a pair of filters with every level of resolution. The profile is decomposed as a consequence into an approximation, A_i , and details, D_i , information. The approximation is then decomposed using the same wavelet decomposition. This is achieved by successive high pass and low pass filtering of the time domain signal. This algorithm of decomposition is mathematically represented as follows:

$$A_j[K] = \sum_{i=1}^n X[i] \times h[2K-i] \quad \text{and} \quad D_j[K] = \sum_{i=1}^n X[i] \times g[2K-i] \quad (3)$$

Where $A_j[K]$, $D_j[K]$ are respectively the outputs of low pass, h , and high pass, g , filters, at the level j ($j \in \{1, 2, \dots, L\}$). L is the total number of the levels of decomposition.

By using the concept of discrete wavelet transform, every profile is analyzed by applying three types of decomposition: the approximations, A , the details, D , and the profile of roughness, B , which is established by: $B_{i+1} = B_i + D_i$, where $B_1 = D_1$. The Figure 1 shows an example for this decomposition at levels 1 and 12. Various families of wavelet transform are available. In our implementation, three wavelet families are used (Symlets, Coiflets, and Meyer).

4. Variance analysis

By applying the three wavelet families (Symlets, Coiflets, and Meyer) with the three types of decomposition (A , B and D), each profile is decomposed in $9 \times L$ profiles where L is the total number of the levels of decomposition. Then the roughness average, R_a , is calculated. The main answer is then to determine if a R_a computed by a given wavelet W and a given decomposition R taken a scale ε discriminates the effect of a given process parameter and, more precisely, which scale of the wavelet

transform will be the more appropriate. Consequently, a $R_a(W, R, \varepsilon)$ is obtained for all profiles. To process to this analysis, we decided to use the variance analysis. The main aspect is to analyze the experimental design by classical analyses of variance. This analyses is then performed at various scales ε and thus for the previously mentioned wavelets families and types of decomposition. The R_a equation is then defined as follows:

$$R_a(R, W, \varepsilon, K_1, K_2, \dots, K_p, n) = \alpha(R, W, \varepsilon) + \sum_{j=1}^p \alpha_{K_j}(R, W, \varepsilon) + \sum_{j=1}^p \sum_{l=j+1}^p \beta_{K_j, K_l}(R, W, \varepsilon) + \zeta_{K_1, K_2, \dots, K_p, n}(R, W, \varepsilon) \quad (4)$$

Where $R_a(R, W, \varepsilon, K_1, K_2, \dots, K_p, n)$ is the value of the R_a parameter of the n th profile when process parameter of p are taken at the levels K_1, K_2, \dots, K_p , for an evaluation length ε . $\alpha_{K_j}(R, W, \varepsilon)$ is the influence on the value of roughness parameter of the j^{th} process parameter at the level K_j and $\beta_{K_j, K_l}(R, W, \varepsilon)$ is the interaction between the j and l process parameters and $\zeta_{K_1, K_2, \dots, K_p, n}(R, W, \varepsilon)$ is a Gaussian noise with a null value.

For every evaluation length ε , wavelet family W and type of decomposition R , all coefficients of the models in Eq. 4 are computed thanks to the least square method.

To test the relevance of the proposed model, the variable F (Fisher-Snedecor) is the ratio of two chi-square distributions with degrees of freedom d_1 and d_2 , respectively, where each chi-square has first been divided by its degrees of freedom, as a consequence, $F(\varepsilon, W, R, p)$ represents the effect of the p process parameter on the value of R_a computed on profile transform at the scale ε with a wavelet W and a decomposition R . For example, considering the p^{th} process parameter using a wavelet W and a decomposition R , a greater F value at the scale ε_1 compared to the scale ε_2 (i.e. $F(\varepsilon_1, W, R, p) > F(\varepsilon_2, W, R, p)$) implies a greater relevance of the scale ε_1 to describe the effect of the p^{th} process parameter.

However, this conventional statistical theory does not take into consideration the fact that a small variation in any score influences the value of the treatment index. That is why the variance analysis was combined with the Bootstrap theory. The aim of this statistical method is to generate N ($N = 100$) equivalent computational sets of data. Each set is generated from a corresponding experimental set of values by performing a permutation with replacement of these values.

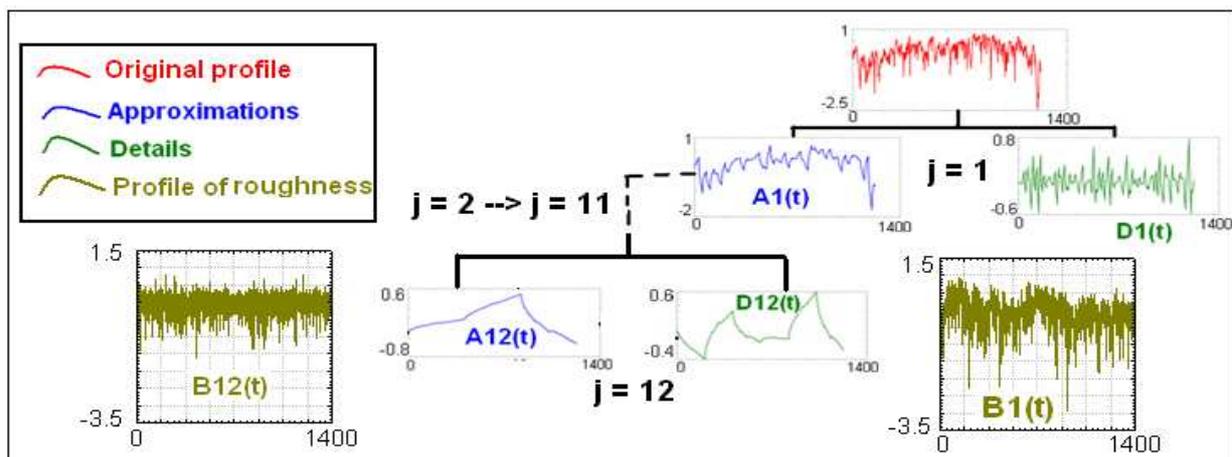


Figure 1: An example of the three decompositions (A, B, and D) for two levels, $j = 1$ and $j = 12$. The total number of the levels of decomposition is $L = 17$

5. Results

Firstly, we have to answer to the followings questions:

- Does the multiscale analysis allow us to find the spatial scale on which abrasion occurs?
- Does the scale of relevance depend on the various process parameters?

- Does the scale of relevance depend on the wavelet choice?
- Does the type of decomposition affect the relevance of the scale?

To answer to these questions, we decide to use the variance analysis previously described in the section 4 and computed the $F(\varepsilon_l, W, R, p)$ values for the different following set (Table 1):

Table 1. Experimental design (Tagushi) of belt finishing process and wavelets configuration (wavelets family, filtering method and resolution scale)	
Factor	Factor Levels
Belt finishing process parameters	Belt feed, Hardness, Hardness versus Belt grid, Hardness versus Pressure, Belt grid, Belt grid versus pressure, Oscillation, Pressure, Rotation, and Time.
Wavelet Family (W)	Symlets, Coiflets and Meyer
Filtering method	A, B, and D.
Resolution scale ε_l (μm)	20, 40, 80, 160, 320, 640, 1280, 2560, 5120, 10240, 20480, 40960, 81920, 163840, 327680, 655360, 1310720.

In a first time, we present the analysis of profiles obtained by the detail decomposition to visualize the relevance of the scale. Thus, we plot the value of F versus the scale ε for the three wavelets. Moreover the influence of each process parameter and three additional interactions were also studied. Figure 2 presents the various evolution of F for each choice of wavelet and process (or process interaction) parameter. It allows us to visualize the relevance of the scale and the effect of all process parameters. It is observed that curves are similar for the three wavelets for any process or process interaction parameter. To sum up, this clearly means that the choice of the wavelet does not influence the value of the most relevant scale. Moreover, this result seems to be verified independently of the choice of the process parameter or associated process parameter interaction.

As it can be observed on table 2, values of relevance do not depend on the wavelets.

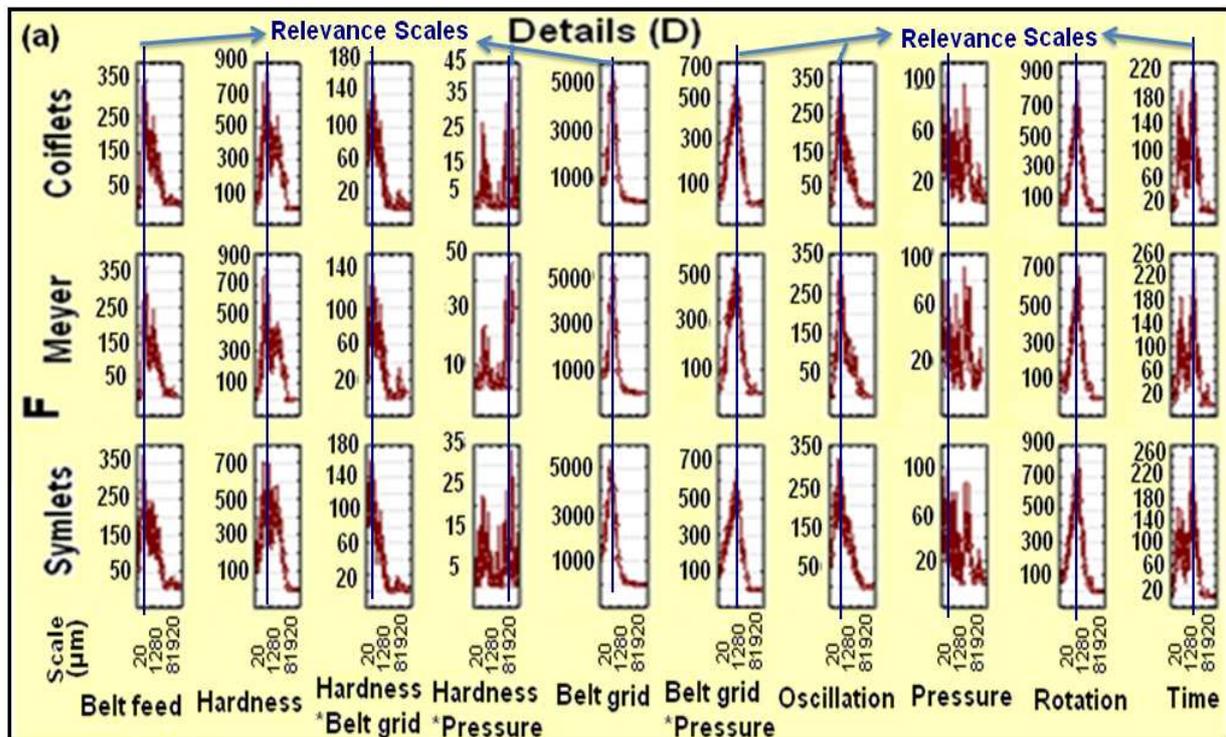


Figure 2: Statistical analysis of the relevance of Wavelets, for each process conditions

Table 2. Mean F value corresponding associated to the experimental design and their associated relevant scales (into bracket, in μm) with the three wavelet families.

	Belt feed	Hardness	Hardness* belt grid	Hardness* Pressure	Belt grid
Coiflets	350 [8,16]	778 [16,64]	179 [8,16]	37 [8192,32768]	5927 [16,32]
Meyer	364 [8,16]	878 [16,64]	135 [8,16]	50 [8192,32768]	6019 [16,32]
Symlets	374 [8,16]	758 [16,64]	179 [8,16]	35 [8192, 32768]	5609 [16,32]
	Belt grid * Pressure	Oscillation	Pressure	Rotation	Time
Coiflets	679 [32,128]	358 [8,16]	117 [8,64]	870 [64,128]	264 [256,512]
Meyer	632 [32,128]	390 [8,16]	109 [8,64]	773 [64,128]	319 [256,512]
Symlets	724 [32,128]	340 [8,16]	108 [8,64]	10860 [64,128]	284 [256,512]

6. Conclusion

Considering a Tagushi experimental design, the scale of relevance is the same for all the wavelets. Any wavelet leads to the same conclusion for this scale, independently of the roughness values. Moreover this allows us to find the most relevant scale range. These scales differ as a function of process or interaction criterion.

Our perspective is to test the relevance of the continuous wavelets and to apply this analysis to a larger database. The influence of roughness of each process or interaction process parameter on surface tribology property will then be studied.

References

- [1] Khellouki A, Rech J and Zahouani H 2007 *Proc. Instit. Mech. Engin. Part B: J. Engin. Manuf.* **221** 1129.
- [2] Rech J and A Moisan 2003 Le toilage: un moyen d'optimisation de l'intégrité des surfaces usinées, 16ème Congrès Français de Mécanique, Nice, France.
- [3] Van Gorp A, Bigerelle M, El Mansori M, Ghidossi P and Iost A 2006 *Int. J. Mater. and Product Tech.*, **38(1)** 16.
- [4] Vetterli M, Kovacevic J and Goyal V 2011 *The world of Fourier and wavelets: Theory, Algorithms and Applications*, (Attribution-NonCommercial-NoDerivs 3.0 Unported License., <http://www.fourierandwavelets.org/book.pdf>)
- [5] Daubechies I 1992 *Ten Lectures on Wavelets* (2nd ed. Philadelphia: SIAM, CBMS-NSF regional conference series in applied mathematics 61).
- [6] Torrèsani B 1995 *Analyse continue par ondelettes* (InterEditions/CNRS Edition, Paris).
- [7] Mallat S 1999 *A wavelet tour of signal processing* (2nd ed., Elsevier, Orlando).