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# Effect of waviness and roughness components on transverse profiles of turned surfaces

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ABSTRACT

This paper presents the authors method of simultaneous analysis of roughness and waviness irregularity components, with the aim of better defining the key qualities and characteristics.

Periodical surface machining traces may be analyzed spectrally, with the irregularity's peaks and troughs being used to define the wave's amplitude.

In this work the standard composition for filtering waviness and roughness components of a surface is utilised.

The method of digitally measuring the irregularity frequency ranges for the purposes of their spectral analysis is first presented. These results are then used to match the frequency ranges with the main irregularity components.

A cumulative amplitude spectrum comprising both irregularity components is proposed to establish the relative contributions of the two components in the frequency spectrum.

Comparative assessment of the error contributions from the form, waviness and surface roughness components gives a more complete image of the analysed surface topography. This also enables simultaneous evaluation of these components in different frequency spectra of the surface's geometrical structure.



## 1. Introduction

The surface geometrical structure (SGS) in its longitudinal and lateral profiles contains the complex character of surface irregularities with roughness, waviness and shape components along the measured length. Such an approach is important in the analysis of surface features and for practical application and evaluation of the technical and qualitative state of a SGS.

For determining the technical quality and practical features of the surface geometrical structure (SGS), all its irregularity profile components should be analysed.

In the classical approach to evaluating surface irregularities, particular irregularity components are filtered into roughness '*R*' and waviness '*W*', and then parameters or functions are specified for them. It is a partial quantification because it determines only the value of waviness or roughness of the profile surface. Practically however, in the surface these components occur together, also being connected with the error of form '*F*'. Combined, these components describe the irregularities of the SGS being analysed. It is more appropriate to quantify them together for the purposes of quality, tribology and surface usage. Moreover, it is necessary to consider irregularity components together and co-evaluate their surface profile contributions.

For some time the authors of the papers [1–3] have seen the need to separate the periodical surface irregularity components by dividing them into waviness and roughness. Recent papers [4–7] lead to decomposition of the components by wavelet methods, which are very useful in some applications and to a lesser extent useful for analysed surfaces.

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Digital signal processing of surface irregularities does not represent the features of real surfaces [8,9]. 3D characteristics of the surface, used more often recently, refers to all areas and means cutting off irregularities [10–12]. If the irregularities are filtered, they undergo the elimination of disturbances or the components are cut off from the SGS, which represent the actual surfaces. Thus, those analyses refer to the filtered components of surface profiles [8,12].

Due to the fact that it is impossible to compare roughness and waviness components using the same parameters, practical and full analyses of those components cannot be performed [13,14].

Some articles show the surface irregularities' characterisation in their length or components' frequency [15–17].

Using the amplitude–frequency functions of a non-filtered and digitally-measured profile, surface irregularities can be applied in a wide-band sense in their spectra [18–20].

Previous work by this author compared the present proposed new method with the standard filtration method. The precise description can be found in Ref. [20].

In the author's opinion, the amplitudes in the frequency band of roughness and waviness components can be co-evaluated and as such this is the core principle presented in this paper and in previous work [21]. This proposed method is of great importance as regards the wide-band evaluation of surface components for technological and quality assurance purposes.

## 2. Irregularity components of turned surface profiles

The broad-band recording is comprised of SGS irregularities, which in metrology are considered selectively by filtering the components: error of form *F*, waviness *W* and roughness *R*. This enables the complex evaluation of SGS to determine its' technical, practical and quality features.

Depending on the quantity and the character of measured surface irregularities, the ISO standards give numerical values of limiting wavelength of form filter $\lambda_F$ as 2.5; 8 or 25 (mm) and numerical values of limiting wavelength of roughness filter $\lambda_R$ as 0.08; 0.25; 0.8 or 2.5 (mm) [22,23].

The term roughness *R* as an SGS component is a limited measure and refers only to the minor range of the lowest heights in relatively small spaces of irregularities. Irregularities in longer periods are denoted as waviness *W* and error of form *F* on the analyzed length of the surface profile and are very important for the accuracy and quality of the surface.

Height and length parameters of particular components of an SGS profile do not describe explicitly and completely the overall surface features or the irregularities in the machining process.

The standard filtration methods cuts out part of the profile signal components so it is then lost. From irregularities measured in this way, standard parameters, distributions and functions are calculated which do not take into account the relations between components in their common formulation. In contrast, spectral analysis presents such possibilities and shows the participation of surface irregularity components in the frequency range presentation. Filtration of any component or a group of components of a digital irregularity signal in spectral analysis and the use of inverse Fourier transform enables the analysis of the filtered components. Such a filtration which is carried out during a standard measurement on a profilometer is also right but it may not correctly separate the roughness and waviness due to the determined 'cut-off' value only (Table 1), as shown in detail in the publication [20].

**Table 1**
Lengths of filtered waves of profile and their frequentative values.

| Cut-off | Sampling length | Frequency range |
|---|---|---|
| $\lambda_c$ (mm) | lr (mm) | $\Delta$v (1/mm) |
| 0.08 | 0.08 | 12.5 |
| 0.25 | 0.25 | 4 |
| 0.8 | 0.8 | 1.25 |
| 2.5 | 2.5 | 0.4 |
| 8 | 8 | 0.125 |

There is an 'excess' of information in the SGS which is either not used or used only in the minor range of band quantifications.

## 3. Amplitude–frequency quantification of surface irregularity components

Surface irregularities play a significant role in qualitative evaluation of the technical and working features of workpieces, especially when form and placement of irregularities in the surface profile is taken into consideration.

The common evaluation of irregularity heights by the standard parameters does not take into account their positioning in the surface profile. Length parameters give only an averaged position of irregularities and lose the periodicity of the disturbances, as generated by the machining system.

When machining with a single-edged tool, a clear circular arc profile of the tool (PT) is generated. This is an irregularity with periodic disturbances generated by the machining system.

Considering the periodic repetition of the tool profile representation on the surface in the period of its feed *f*, the frequencies of the generated traces can be analysed. Then the irregularity heights may be analysed by means of amplitude in the spectral analysis of the surface profiles. To perform the amplitude–frequency analysis of such a signal it is best to use the procedure of Fast Fourier Transformation (FFT), as in Ref. [18]. Irregularity values are thus assigned by the formula below:

$$X(k) = \sum_{n=0}^{N-1} x(n) \exp\left[-j\frac{2\pi kn}{N}\right], \quad (1)$$

and then the amplitude spectrum by the following equation:

$$A(k) = \frac{2}{N}|X(k)|, \quad (2)$$

where *X(k)* is the components of Fourier transformation, *A*(*k*) is the discrete amplitude, *x(n)* is the *n*-order sample