Selecting software filter settings for evaluating periodic and aperiodic surface roughness

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Abstract: A lot of properties depend on the quality of the surface, such as efficiency, reliability, functional properties, external appearance, and, last but not least, the cost of the entire production process. And if there is an inaccurate assessment during evaluating the integrity of the surface, especially for assessing roughness, this can lead to fatal problems in the actual use of the inspected part in practice. In order to meet all the requirements of the evaluation of the surface structure, it is necessary to keep up with the times and always have control of new possibilities and knowledge from the fields of measuring and evaluating the integrity of the surface, and being able to implement this knowledge into real conditions of use.

In the area described in this article, the selection of software filters, this is not always the case. The main reason is low awareness and the great complexity of choosing a suitable combination of possible procedures and techniques for setting software filters.

Therefore, a comprehensive methodology for the selection of software filters for both periodic surfaces and subsequently for aperiodic surfaces was created and is described in this article. Its coherence and graphical simplicity are prerequisites for quick understanding and easy implementation of the methodology in common practice.

The methodology for the selection of the software filter has 4 steps for periodic surfaces and 5 for aperiodic surfaces, which help the user of the profilometer, whether contact or contactless, to correctly set the device. Furthermore, the methodology should ensure that two people measure the same, or at least in the order of hundredths of the same results (values), which currently is not quite the case.

Keywords: Roughness, Evaluation of integrity surface, Periodic surface, Aperiodic surface, Hardware filter, Software filter.

1. Introduction

The development of measurements and evaluation of the surface structure has seen significant qualitative technical progress in recent years. Leading manufacturers of measuring technology have actively responded to the new requirements for the quality of functional surfaces of components made of advanced construction materials combined with high accuracy of dimensions, shape and mutual position of often small functional surfaces [1]. The development of measuring technology is significantly influenced by the technical needs of users and their economic possibilities.

Given that single-purpose measuring devices are used to check the surface structure; it is clear that their manufacturers are involved in increasing the quality of metrology. The result of the comprehensive development is not only an increase in the technical level of existing methods for measuring and
evaluating the surface structure but also the preparation of new methodologies, measuring systems and systems for evaluating the surface structure [1]. But despite this progress, in practice, we still encounter the opinion that the evaluation of surface integrity is unnecessary and does not bring any further knowledge to the possible comprehensive optimization of the production of a given part or component.

However, from the point of view of its expertise at evaluation, it is clearly demonstrated that surface integrity describes the relationship between the geometric properties of a surface and physical properties such as residual stresses, hardness and microstructure of the material [2]. Furthermore, it reflects the conditions under which the functional surface is created, takes into account the effects of technological methods on the quality of the machined surface and puts them in relation to the functional requirements for the entire product.

First is necessary to describe, what is here means by the surface roughness. The basic definition according to EN ISO 4287 [3] (describing terms, definitions and surface parameters) stipulates that roughness is the sum of surface irregularities within a relatively small distance, which inevitably arise during production or its influence [4].

If we look at the real surface, we can find there are two types of surface. The first is micro-roughness (which is the surface roughness defined above, which is caused by the traces left by the cutting tool or abrasive) and the second is macro-roughness (which is also called surface waviness and is most often caused by system vibrations in the Machine - Tool - Work piece - Environment). In the case of machined surfaces, these irregularities overlap and must be filtered out (i.e. divided into surface roughness and waviness).

The individual irregularities differ from each other mainly in their spacing and different influences on the surface function. For this reason, it is necessary to separate them during their analysis. The separation of the components of the surface structure is performed by filtering them in order to determine the specific roughness parameters (Ra, Rz, Wt, etc.) from the measured surface profile (basic profile). This is necessary in order to separate the roughness from the other irregularities present on the measured surface [6,7].

**2. Data filtering**

The most basic and simplest is hardware data filtering, which does not need any other equipment apart from the basic equipment of the device. Thanks to these filters, known in practice as ‘cut-off’ filters, the
roughness-waviness-shape of the surface are separated. See figure 2.

![Figure 2. Function of cut-off filter][7]

The filters have the same transmission characteristics but different wavelength limits. They transform the profile so that it does not contain irregularities with larger pitches, such as waviness or other shape deviations, which would distort the actual roughness measurement. For the correct functioning of the filter, it is necessary to determine the values of the basic length, according to which the examined surface is filtered. The profile filter divides profiles into longwave and shortwave components [8,9].

- Profile filter - $\lambda_c$ - "Filter defining the interface between roughness and shorter components of waves present on the surface" [3].
- Profile filter - $\lambda_s$ - "Filter defining the interface between roughness and waviness components" [7].
- Profile filter - $\lambda_f$ - "Filter defining the interface between the corrugation and the longer components of the waves present on the surface" [3].

The principle of deploying hardware filters can be seen in the following figure 3 in the area framed in blue. Until now, we have only dealt with the issue of hardware data filtering. However, this part of data filtering is relatively well described in standards and methodologies for this area and is not the main area of interest of this work.

However, the main goal of the work, which is described briefly in the article, is the issue of data filtering using software filters [5,8]. Thus, the article focuses on the red-framed area in figure 3. These filters can be applied only after the separation of the individual components of roughness-waviness-surface shape.

![Figure 3. System of filtering data form the primary profile][7]

According to the EN ISO 16610-1: 2015 standard, these filters are divided into 2 basic areas.

- 2D profile filter.
- 3D spatial filter [6].
Both types of software filters have other subgroups according to the mathematical procedure of calculation.

- Linear - ČSN EN ISO 16 610-20.
- Morphological - ČSN EN ISO 16 610-40.
- Robust - ČSN EN ISO 16 610-30 [6].

Table 1. Table with the dividing of software surface roughness filters [6].

| Filter | Type        | Category       |
|--------|-------------|----------------|
| A = spatial 3D | M = Morphological |
| F = Filter | R = Robust    |
| P = Profile 2D  | M = Morphological |
|         | R = Robust    |

From the options that are described in table 1, only the basic representatives from each category were selected for further description. These filters were also subjected to a more detailed description, see article [7].

Due to the fact that the surface structure depends in most cases on the machining method used, two types of marks can appear on the surface. [9] The direction of unevenness on the surface can be either significant (periodic) or indistinct (aperiodic). Figure 4. The periodic surface is created during turning, milling, drilling, etc., i.e. when the tool creates grooves on the surface in a certain direction. The aperiodic surface is created during casting, forging, etc. Somewhere on the border there are finishing methods such as grinding, lapping or polishing, which at a certain moment create both surfaces on the work piece surface [11].

![Figure 4. (a) Periodic surface. (b) Aperiodic surface [4].](image)

When creating the methodology for choosing a software filter, first only the periodic surface was considered. This type of surface was chosen due to its more frequent occurrence in technical practice. The methodology described later in the article was created based on the extensive tests described and evaluated in the thesis, see [7,10].

3. Methodology of software filter selection - periodic surface

The methodology is divided into 4 steps. The first step of the methodology is to choose the optimal size of the stylus tip. Here, looking at figure 6 it is clear that the choice of the tip depends on the expected size of the tested surface and the type of roughness parameter which will be used for evaluation. From the test, it was verified that even with the combination of a worn tip with a suitable software filter it is not possible to achieve the same results as with new tips. Therefore, only measurements performed with new tips were included in the second part of the test. After summarizing and final evaluation of this part of the test, it was decided that only a 2 µm tip would be used for further tests.
In the second step of the machine setup procedure, it is necessary to select the optimal distance between the scanned points. The procedure is a compromise between the small variance of the measured value and the value of the distance of the measured value from the standard value.

In the third step, the stylus feed rate is selected for scanning the primary profile. Based on the findings of this test, information emerged that the scan rate has no effect on the Rsm parameter. The results for the parameters Ra, Rv and Rz using scanning speeds up to 1.07 mm/s are almost identical. At higher speeds, the inaccuracy of the measured data increases for all three parameters and also increases the variance of values. Therefore, it is not recommended to use a feed rate value greater than 1.07 mm/s.

The fourth (last) step of the methodology is the choice of software filter. Here again, it is important to find a compromise between the smallest variance of values and the maximum measured value.

A summary of the procedure for setting up the machine is shown in figure 5.

**Figure 5.** Steps for setting during a measuring a periodic surface.

4. **Methodology of software filter selection - aperiodic surface**

The second part of the research focuses on the creation of a methodology for the selection of software filters for an aperiodic surface. One of the tasks of the research was to create a new or supplement the existing methodology for choosing a software filter for an aperiodic surface.

As with periodic surface tests, all test evaluations were performed according to the "VDA" rule. The "VDA" rule assumes that if the maximum measured value meets the required maximum value in the drawing, the entire surface is OK. In the case of tests performed to create a methodology for selecting software filters, the value specified in the calibration sheet for the given tested standard was taken as the limit value. All processing of measured data was performed with the support of extensive statistical analysis by Ing. Marková. Based on the repetition of all the tests performed on periodic surfaces, it was decided only to supplement the existing methodology for selecting software filters for periodic surfaces.

The existing methodology was supplemented by one whole step and several other important findings for the evaluation of aperiodic surfaces. The most important thing was the addition of the step – the choice of the scanning direction. This point indicates the need to measure aperiodic surfaces in several directions on the surface traces, at different locations on the test sample, as described in article [8].
Another important finding for measuring aperiodic surfaces is in the step of choosing a software filter. We found that, in contrast to the periodic surface, the most suitable filter for aperiodic surfaces was EN ISO 16610-31 (Gaussian robust filter).

A summary of the procedure for setting up the machine is shown in figure 6.

5. Conclusion

We define texture, or in other words the structure of a surface, as an area with a huge set of grains, which are located between the surroundings and the surface of the material, i.e. a fixed part. The surface is an extremely complex system where there are repeated (periodic) or random (aperiodic) deviations from the ideal geometric shape of the surface. These deviations can be expressed in several ways, the oldest is the line profile, the most common nowadays is probably the expression of the three-dimensional topography of the surface. According to the size of the pitch of the respective irregularities, the surface structure is divided into three components. The basic profile determines the component with the largest pitch of inequalities and is called the P-profile. The component with the smallest pitch is determined by the surface roughness, which in turn is referred to as the R-profile. And the component between the largest and smallest spacing is called the surface waviness, W-profile. [11]

The composition of these components on the surface generally directly affects the functional properties of the surface. The often expressed view of the surface - "the smoother the better" - may not always be correct, as there are other factors. E.g. to ensure lubrication, depressions must be left on the surface to hold the lubricating medium. In all cases, it is necessary to assess the economic side of things - the increase in the cost of producing a very "smooth" surface may not always correspond to the functional benefit. Therefore, the functional use of the surface is decisive. The requirements for surfaces...
that are shifted relative to each other will be different from the requirements for surfaces forming sealing surfaces or for surfaces intended for subsequent painting, etc. It follows from the above that measuring and evaluating the surface structure is very important from a practical point of view.

Much has been written and said about assessing the integrity of the surface. However, most of these articles and professional publications focus on the evaluation of the surface of periodic surfaces, which is logical due to their representation in technical practice. However, the aim of the article is to point out the difference between measuring the surface roughness of periodic surfaces (in technical practice the most common surfaces) and non-periodic surfaces, using the above-described methodology of software filter selection for both types of surfaces.

Methodologies for periodic surfaces and subsequently for aperiodic surfaces is described in this article. The software filter selection methodology has 4 steps for a periodic surface and 5 steps for an aperiodic surface which direct the user of the profilometer, whether contact or contactless, to the correct setting of the device. Furthermore, using the methodology should ensure that two people measure the same or at least in the order of hundredths of the same results (values), which is currently not always the case.

The methodology of choosing a software filter for a periodic surface was supplemented by one whole step and several other important findings for the evaluation of aperiodic surfaces. The most important thing is the addition of the step – the choice of the scanning direction. Another important finding for measuring aperiodic surfaces is in the step of choosing a software filter, and the finding that, in contrast to the periodic surface, the most suitable filter was EN ISO 16610-31 (Gaussian robust filter).

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