STYLUS BASED EVALUATION OF THE SURFACE ROUGHNESS

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This paper deals with problems in determining surface roughness values. The process of determining surface roughness values is a relatively difficult task. In this process, it is necessary to set the measurement conditions, which have a huge impact on the measurement uncertainty, and neglecting this process can cause a complete degradation of the measurement and evaluation result. Certain changes in this process are defined by new standards that have been approved to guide this process. The development of the methodology is very necessary in this area in order to obtain reliable data on surface roughness values.

KEYWORDS

roughness, gauges, uncertainty, calibrator

1 INTRODUCTION

This article focuses on the issue of surface roughness assessment. Basically, two large groups of methods are used, i.e., contact methods (also called as stylus-based methods) or non-contact methods for determining surface roughness. Both groups have their advantages and disadvantages. The stylus-based method is a relatively fast contact method that can be implemented using relatively cheaper and more affordable devices and is thus more often used for the process of evaluating surface roughness. However, the non-contact method of determining surface roughness is also more often used in research projects, but it is more expensive in terms of instrumentation and software. In this article, we continue to focus on the stylus-based method (Fig. 1), which is more widespread for ordinary users [EA-4/02 1999, Hogan 2019, Kumar 2019, Suder 2021, Duplak 2023].

Figure 1. Surface roughness tester

In this method (Fig. 2), the touch sensing tip moves along the evaluated surface, and the irregularities that are determined in this way are the basis for processing the values of the individual surface roughness values. Here, however, there is a limitation in that the sensing tip itself has its own dimensions, which affect the process of identifying the unevenness of the surface. This method therefore has its limitations and cannot capture irregularities smaller than the sensing tip itself. Most surface roughness testers have a stylus tip in the form of a cone with a radius at the end of the tip (Fig. 3).

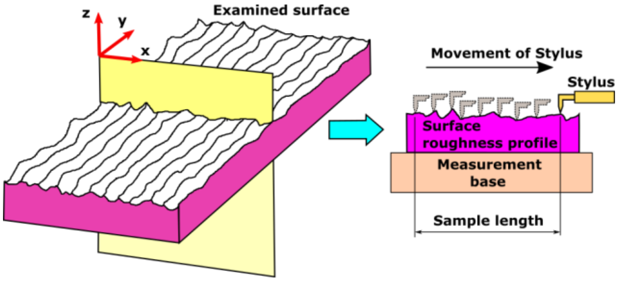

Figure 2. Stylus based surface roughness tester principle

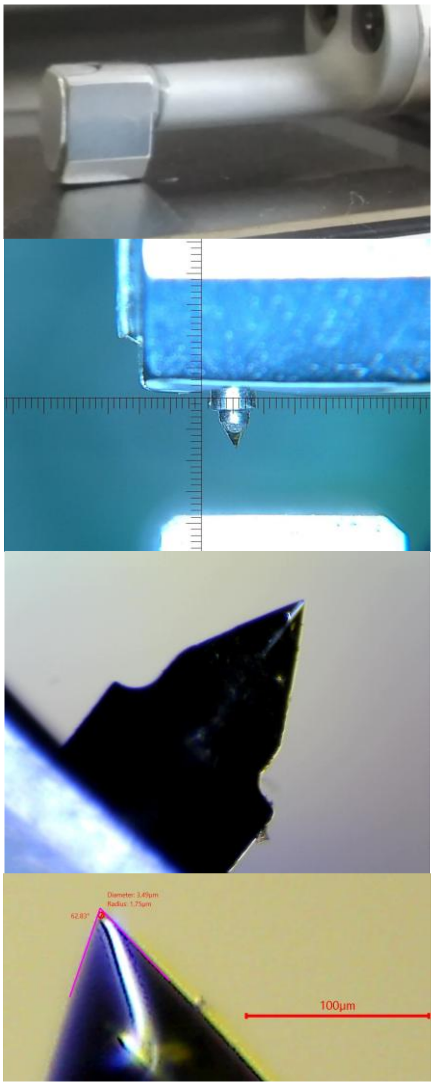

Figure 3. Stylus tip of surface roughness tester

The terminology and methodology of measurement and evaluation of surface roughness values was established in the standards EN ISO 4287 [ISO 4287: 1997] and EN ISO 5436 [ISO 5436-1: 2000]. In summary, these methods are called Geometrical Product Specifications (GPS). When evaluating the surface roughness, these standards took into account the method of production technology of the evaluated surfaces of the products. When assessing surface roughness values, we therefore distinguished between periodic and non-periodic surface roughness profiles. According to the expected value of arithmetic mean height of roughness (Ra) or according to the value of Mean spacing of the profile elements (Rsm), the measurement parameters are then determined as a cut-off filter *Lc* or also referred to as (*λc*). This approach has been shown to be discriminatory and in ISO 21920-1, ISO 21920-2, ISO 21920-3 no longer distinguishes between periodic and non-periodic surface roughness profiles.

In this article, we will further deal with the most frequently evaluated quantity of surface roughness, namely Arithmetical mean height of the roughness (*Ra*).

Surface roughness is a summary characteristic of surface unevenness, which is described by several quantities [ISO 5436-1: 2000, JCGM 100 2008, JCGM 104 2009, JCGM 200 2012, Whitehouse 2004, Kelemenova 2020, Krenicky 2022]. From the point of view of aesthetics, it affects the overall appearance of the product. In terms of functionality, there are cases when a very small surface roughness is required to reduce friction, for example, or it is necessary to increase the roughness in order to achieve higher braking efficiency. The roughness of the surface is also important as a preparation for surface treatment of products [Straka 2022]. In the field of biomedical engineering of implants, surface roughness is important mainly for better implementation of the implant with living tissues. When it comes to floor coverings, the roughness of the surface is important to prevent people from slipping and falling. The soles of the shoes must also achieve a certain surface roughness. It is equally important to assess the roughness of the surface on road surfaces so that vehicle braking is effective and safe. Surface roughness in mechanical devices such as bearings, pistons in combustion engine cylinders, and the like require as little surface roughness as possible to minimize frictional forces and energy to overcome this friction.

Therefore, the assessment of surface roughness is a key task in many fields and this was the main motivation for creating this work [Koniar 2014, Bozek 2016, Mascenik 2016, Stejskal 2016, Pavlasek 2018, Saga 2019 & 2020, Tlach 2019, Blatnicky 2020, Nikitin 2020, Peterka 2020, Hortobagyi 2021, Kelemen 2021, Kelemenova 2021a,b, Klarak 2021, Kuric 2021, Pivarciova 2021, Lestach 2022, Mikova 2022, Bratan 2023, Fernandez-Lucio 2023, Machac 2023, Romancik 2024, Vagas 2024].

2 SETTING PARAMETERS FOR SENSING SURFACE ROUGHNESS AND EVALUATING SURFACE ROUGHNESS VALUES

The surface profile of the surface roughness is significantly influenced by the production technology used and mostly contains the waviness of the profile, which is the carrier of minor surface irregularities (Fig. 4), which characterize the surface roughness, and which need to be evaluated but without the influence of the waviness of the surface profile. The waviness of the profile is therefore a disturbing influence for the assessment of surface roughness, and it is necessary to remove it from the measured surface profile using a cut-off filter *Lc* and to evaluate this surface profile without this influence of waviness.

Standard surface roughness testers have a cut-off filter setting *Lc* with nominal values of 0.08 mm, 0.25 mm, 0.8 mm, 2.5 mm, 8 mm and 25 mm. The task of the operator is to correctly select the cut-off filter value. Another parameter is the speed of the stylus tip, which can be set to three different values of 0.25 mm/s; 0.5 mm/s; 0.75 mm/s. Furthermore, it is possible to set a specific standard for the evaluation of ISO, DIN, JIS, ANSI, VDA surface roughness values. It is also possible to set other parameters for the data filtering process. All these settings greatly affect the result of the surface roughness evaluation process.

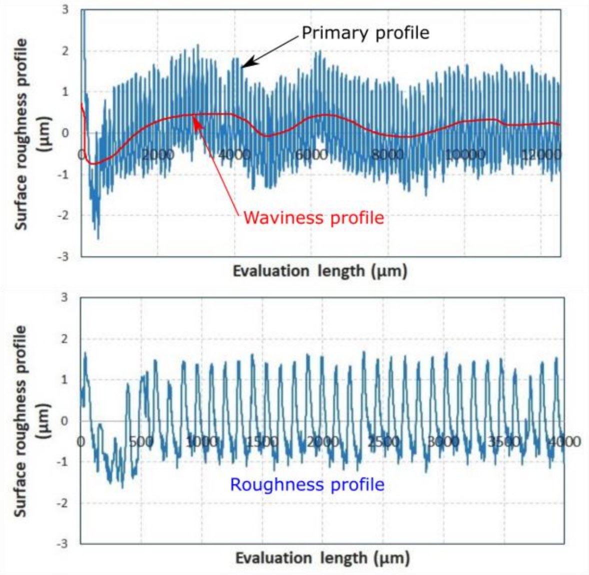

Figure 4. Surface profile with profile waviness and after applying the filter without the effect of surface waviness

Standards ISO 3274 [ISO 3274: 1996], ISO11562 [ISO 11562: 1996] list the recommended values of cut-off filters, stylus tip size and sampling spacing (Tab. 1).

Table 1. Recommended cut-off filter values, stylus tip size and sampling spacing according to ISO 3274, ISO11562 standards

Cut-off ***λc*** (mm)	Cut-off ***λs*** (μm)	Roughness cut-off wavelength ratio ***λc* / *λs***	r_{tip} max (μm)	Maximum sampling spacing (μm)
0.08	2.5	30	2	0.5
0.25	2.5	100	2	0.5
0.8	2.5	300	2	0.5
2.5	8	300	5	1.5
8	25	300	10	5

The EN ISO 4288 standard recommends for non-periodic filter setting profiles and recommends 5 section lsc lengths for the assessment of surface roughness values (Tab. 2). Here the problem arises that in Table 2 there are recommended values for specific values of Ra, which we do not always know, and we want to determine it using the process of measuring the surface profile and evaluating it using a cut-off filter.

Table 2. Recommended filter settings for non-periodic filter profiles for evaluating surface roughness values according to the EN ISO 4288 standard.

Arithmetical mean height of the roughness profile ***Ra*** (mm)	Section length of profile ***lsc*** (μm)	Evaluation length of profile ***lm*** (mm)
Ra < 0.02	0.08	0.4
0.02 < *Ra* ≤ 0.1	0.25	1.25
0.1 < *Ra* ≤ 2	0.8	4
2 < *Ra* ≤ 10	2.5	12.5
10 < *Ra* ≤ 80	8	40

Recommendations for setting parameters of the surface roughness tester according to individual standards for non-periodic profiles are more clearly summarized in graphic form (Fig. 5).

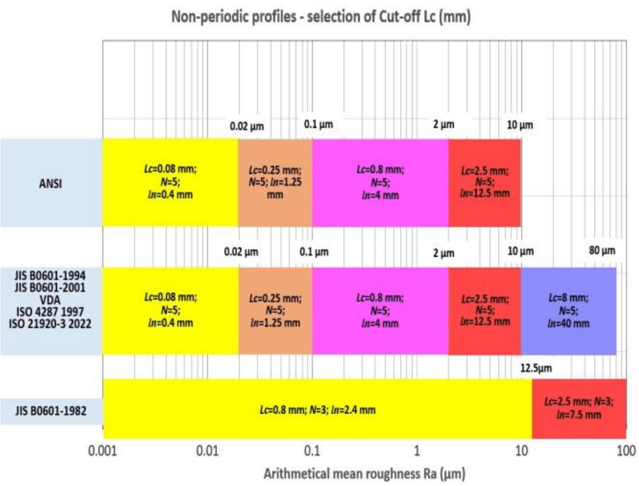

Figure 5. Recommendations for setting parameters of the surface roughness tester according to individual standards for non-periodic profiles

In the case of periodic profiles, the influence of the displacement of the cutting tool during the formation of the surface of the component is more significant, and the influence of waviness is much greater, and therefore, according to the ISO 4288:1996 [ISO 4288: 1996] standard, it is recommended to set the parameters for sensing the surface profile and evaluating the surface roughness values according to the value Mean spacing of the profile elements Rsm (Tab. 3).

More clearly, the recommended settings of the surface profile sensing parameters and the evaluation of surface roughness values for periodic surface profiles according to the ISO 4288:1996 standard are summarized in graphic form (Fig. 6).

Table 3. Recommended settings of surface profile sensing parameters and evaluation of surface roughness values for periodic surface profiles according to the ISO 4288:1996 standard

Mean spacing of the profile elements Rsm (mm)	Roughness sampling length *lr* (mm)	Roughness evaluation length *ln* (mm)
0.013 < *RSm* ≤ 0.04	0.08	0.4
0.04 < *RSm* ≤ 0.13	0.25	1.25
0.13 < *RSm* ≤ 0.4	0.8	4
0.4 < *RSm* ≤ 1.3	2.5	12.5
1.3 < *RSm* ≤ 4	8	40

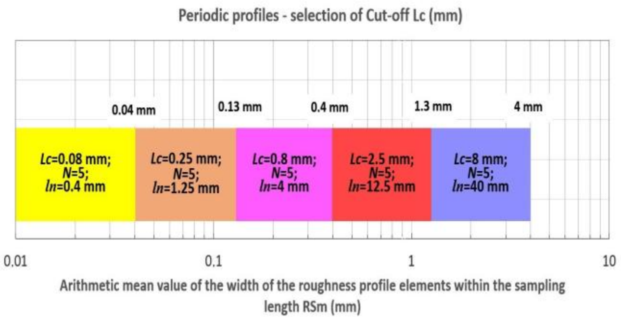

Figure 6. Recommended settings of surface profile sensing parameters and evaluation of surface roughness values for periodic surface profiles according to the ISO 4288:1996 standard.

The ISO 4288:1996 [ISO 4288: 1996] standard was replaced in 2021 by the ISO 21920-3:2021 standard. The whole series of standards ISO 21920-1 [ISO 21920-1: 2021], ISO 21920-2 [ISO 21920-2: 2021], ISO 21920-3 [ISO 21920-3: 2021] introduces no discrimination of periodic and non-periodic profiles of the surface of the evaluated components according to the value of the quantity *Ra* (Tab. 4).

Table 4. Recommended settings of surface profile sensing parameters according to the ISO 21920-3:2021 standard

Setting class Sc	Sc1	Sc2	Sc3	Sc4	Sc5
Parameter *Ra* (µm)	*Ra*≤0.012	0.012<*Ra*≤0.006	0.06<*Ra*≤ 1.2	1.2<*Ra*≤ 6	*Ra*>6
Profile L-filter nesting index *Nic* (cut-off *λc* (*Lc*) for *R*-parameters) (mm)	0.08	0.25	0.8	2.5	8
Evaluation length *lm* (mm)	0.4	1.25	4	12.5	40
Profile S-filter nesting index *Nis* (cut-off λs) (µm)	0.8	0.8	2.5	8	25
Maximum sampling interval *dx* (µm)	0.15	0.15	0.5	1.5	5
Maximum tip radius r_{tip} (µm)	2	2	2	5	10
Section length *lsc* (mm)	0.08	0.25	0.8	2.5	8
Number of sections *nsc*	5	5	5	5	5

Recommended settings of surface profile sensing parameters according to the ISO 21920-3:2021 standard is better displayed in graphic form (Fig. 7).

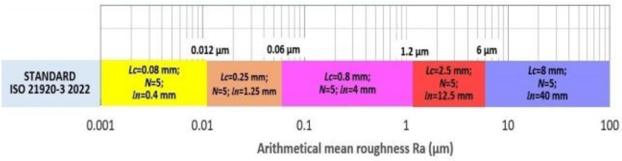

Figure 7. Recommended settings of surface profile sensing parameters according to the ISO 21920-3:2021 standard.

3 EXPERIMENTAL ESTIMATION OF ARITHMETIC MEAN HEIGHT OF ROUGHNESS Ra

According to the standards ISO 21920-1 [ISO 21920-1: 2021], ISO 21920-2 [ISO 21920-2: 2021], ISO 21920-3 [ISO 21920-3: 2021], the methodology for selecting the parameters for measuring the surface profile is uniformly determined for all types of surfaces, but the basic information is the knowledge of the quantity Ra, which we want to determine by this process. One way is to perform measurements at all settings of the surface tester, but this can be extremely laborious and time-consuming. The second option is to make an initial estimate of the quantity Ra using a non-contact method (Fig. 8) and then choose the correct setting of the measurement and evaluation process accordingly (Fig. 9).

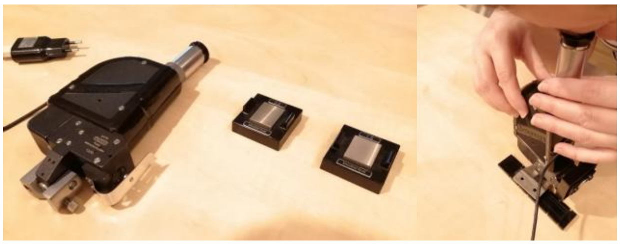

Figure 8. Optical comparison method using a microscope.

In this work, an optical comparison method using a microscope (Fig. 8) was chosen, which enables the simultaneous display of the measured surface and the surface of the surface roughness standard for the relevant type of technology that was used for the product under consideration. The result (Fig. 9) is an approximate value of *Ra*, which is an input parameter in the design of the surface tester setup. This process will significantly simplify the methodology that is defined in the standards for the geometric specification of products.

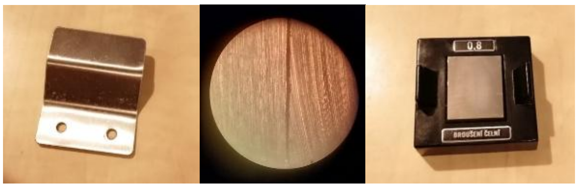

Figure 9. Estimation of surface roughness value - evaluated product; view into the microscope objective; standard of surface roughness

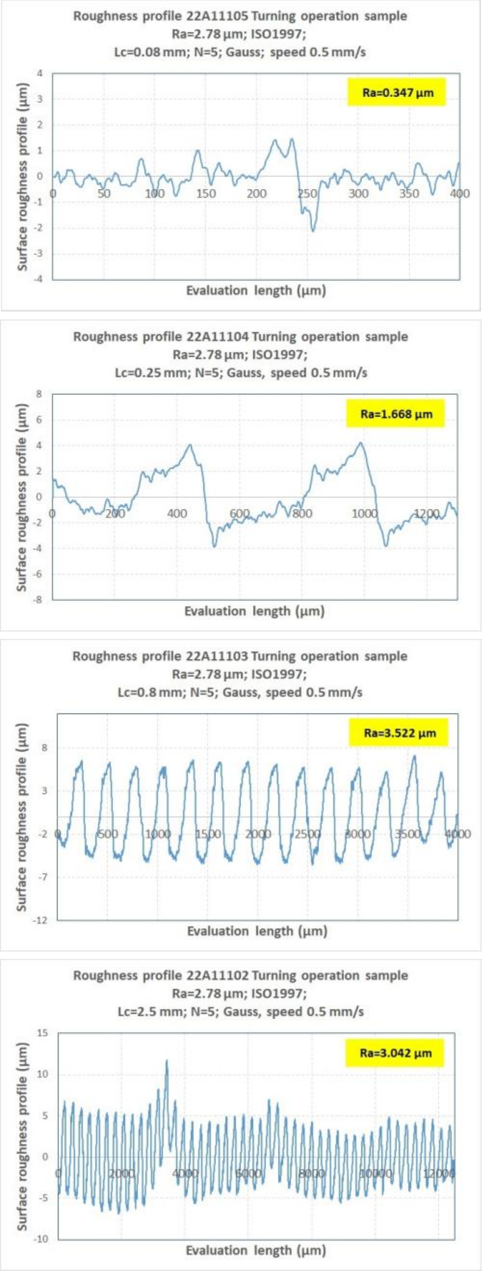

Figure 10. Profiles of surface roughness obtained when measuring at the same measurement location under the same conditions but with different cut-off filter settings.

Figure 10 shows a sample of surface roughness for a part made by turning technology. For experimental purposes, the surface profile was measured, and *Ra* was evaluated for all settings of the cut-off filter.

Profiles of surface roughness (Fig. 10) were obtained when measuring at the same measurement location under the same conditions but with different cut-off filter settings (*Lc* = 0.08 mm, 0.25 mm, 0.8 mm and 2.5 mm).

The curves show the influence of waviness on the displayed surface unevenness profile. The most significant effect of the waviness is visible in the last measurement at the largest value of the cut-off filter. Such an analysis is also applicable for determining the appropriate settings of the measurement parameters.

4 CONCLUSIONS

The proposed methodology makes it possible to effectively determine the surface roughness values of the evaluated products. The use of surface roughness estimation is a relatively simple way to solve the problem of determining the parameters for measuring the unevenness profile of the product surface and determining the surface roughness values. An older optical microscope was used, but it is fully functional, so it is a relatively cheap way of solving this process. Sample sheets for various types of technologies were used as standards of surface roughness, which can be quickly confronted with the evaluated surface of the product.

In the future, it will be necessary to verify these samples of surface roughness, and the microscope used will need to be digitized.

In many works, knowing the state of surface roughness is very important because the size of the frictional forces in individual functional surfaces is directly related to it. And so these knowledge will find application in many other works [Vagas 2022, Vagas 2023, Virgala 2022a, Virgala 2022b, Zelnik 2021].

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