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Assessment of surface texture – Guidance and general information

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Foreword

Publishing information

This British Standard is published by BSI and came into effect on 30 November 2010. It was prepared by Technical Committee TDW/4, *Technical product realization*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This British Standard supersedes BS 1134-1:1988 and BS 1134-2:1990, which are withdrawn.

Information about this document

This is a full revision and amalgamation of BS 1134-1:1988 and BS 1134-2:1990. BS 1134:2010 is also based on the *Best Practice Guide: Measurement of surface texture using a stylus instrument*, NPL, 2001, with the written agreement of the National Physical Laboratory.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

0 Introduction

0.1 General

Often the surface of a work piece appears flat and smooth to the human eye. By running a finger across the surface it can feel smooth, but examining this surface under a magnifying device reveals a complex structure, which can be the result of factors such as material structure and paint on the surface, as well as the manufacturing processes to which the surface has been subjected. Surface structure is called texture. Surface texture often affects the performance, quality and service life of the product. It is critical in machine processing, as in many other disciplines, to evaluate and control the surface characteristics of many products. To control surface texture, it first has to be measured. Measuring during the manufacturing cycle can influence decisions taken on machining systems and processes. This allows them to be controlled and optimized, thereby improving the product. Measuring surface texture at the end of the cycle helps engineers to form an opinion about the components' performance capability.

Surface texture gives components various characteristics. The lifetime of mating surfaces, such as shafts and bearings is dependent on surface texture. Where a shaft is subject to load reversals, it can become worn and its lifetime is reduced. Surface irregularity is often at the root of component failure, therefore, the more consistently flat the surface texture, the longer the life of the component.

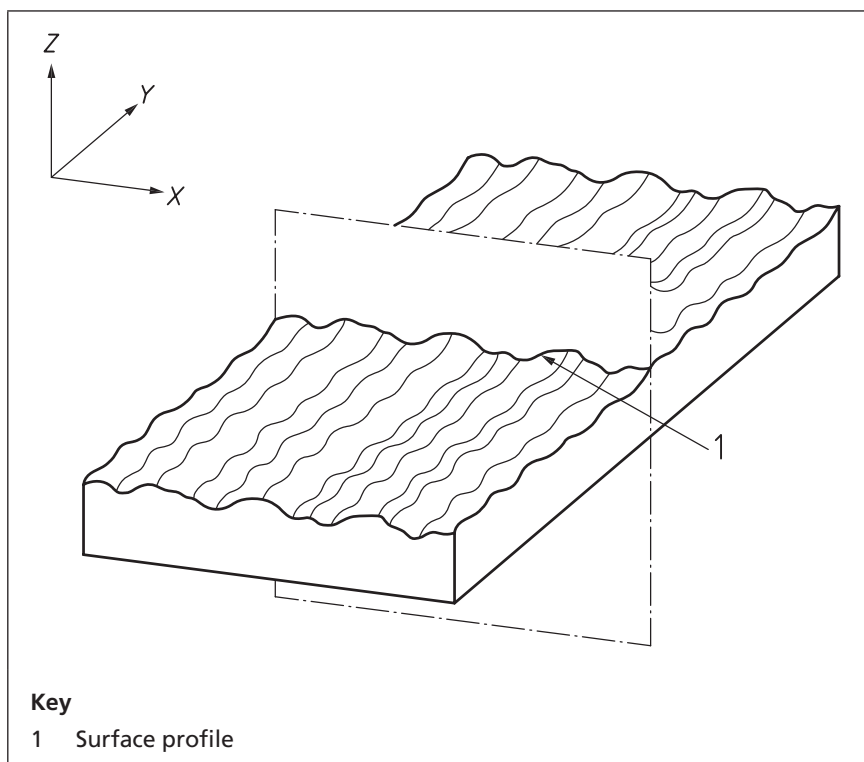
The useful life of a product is governed by the rate of wear of its component parts. The rate of this wear depends on the surface area with which it is in contact and the characteristics of the materials. A rough surface with large peaks has less contact area and wears at a quicker rate than a surface with a smooth top.

0.2 Surface profile measurement

When measuring and characterizing surface texture, use is made of the rectangular co-ordinate of a right-handed Cartesian set, in which the x axis provides the direction of trace, the y axis lies nominally on the real surface, and the z axis is the outward direction from the material to the surrounding medium (see Figure 1).

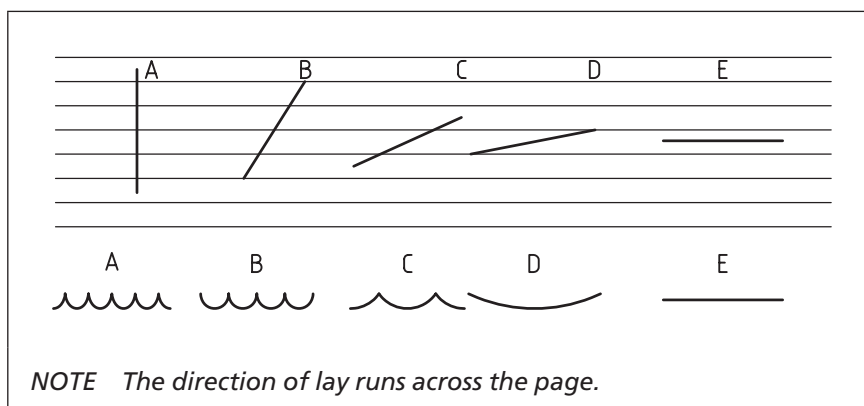
The surface profile results from the intersection of the real surface by a specified plane. It is typical to select a plane with a normal that nominally lies parallel to the real surface. BS EN ISO 13565-1 specifies that the traversing direction for assessment purposes shall be perpendicular to the direction of the lay unless otherwise indicated. The lay is the direction of the predominant surface pattern. Lay usually derives from the actual production process used to manufacture the surface and results in directional striations across the surface. The appearance of the profile being assessed is affected by the direction of the view relative to the direction of the lay. Determinations of surface texture are made at 90° to the lay. Where the direction of the lay can affect the function of the surface, it is important to specify this on an engineering drawing detailing the type of lay and the direction (see BS EN ISO 1302).

Figure 1 Co-ordinate system



For machining processes that produce straight, circular or radial lays, the direction in which to make the measurement can usually be observed by visual inspection of the surface. Where it is not possible to form an opinion as to the direction of the lay then it is usual to make measurements in several directions, and to accept the maximum value as a roughness height parameter. Some surfaces might possess no lay direction at all (for example, components that have been sandblasted) and in this case the same value for a surface texture parameter is measured irrespective of the direction of measurement of the stylus. Figure 2 shows how the effect of the lay on the measured surface texture depends on the direction in which the measurement is taken.

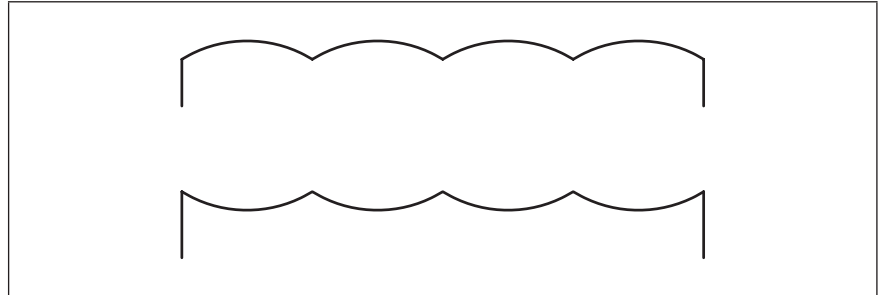
Figure 2 The effect of measuring in different directions to the surface lay



When measuring surface texture, it is advisable to take care when interpreting the results; even two surfaces having the same surface texture parameter value can have different functional characteristics. Figure 3 shows two surfaces with the same R_a value but different

functional characteristics. While the upper surface would perform well as a bearing, the lower surface wears more quickly due to the sharp spikes on the surface.

Figure 3 **Two surfaces with the same R_a value but different functional characteristics**



1 Scope

This British Standard gives guidance on the measurement of surface texture using a stylus instrument. This standard describes the way in which measurements can be taken and how to interpret the results. The guide also gives recommendations for the use of comparison specimens.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 1302, *Geometric product specifications (GPS) – Indication of surface texture in technical product documentation*

BS EN ISO 3274, *Geometric product specifications (GPS) – Surface texture – Profile method: Nominal characteristics of contact (stylus) instruments*

BS EN ISO 4287, *Geometric product specifications (GPS) – Surface texture – Profile method: Terms, definitions and surface texture parameters*¹⁾

BS EN ISO 4288, *Geometric product specifications (GPS) – Surface texture – Profile method: Rules and procedures for the assessment of surface texture*

BS EN ISO 5436-1, *Geometrical product specifications (GPS) – Surface texture: Profile method; Measurement standards – Part 1: Material measures*

BS EN ISO 5436-2, *Geometrical product specifications (GPS) – Surface texture: Profile method; Measurement standards – Part 2: Software measurement standards*

BS EN ISO 9000, *Quality management systems – Fundamentals and vocabulary*

¹⁾ This standard also gives an informative reference to ISO 4287:1984 and ISO 4287:1997.

BS EN ISO 11562, *Geometrical product specifications (GPS) – Surface texture: Profile method – Metrological characteristics of phase correct filters*

BS EN ISO 12085, *Geometric product specifications (GPS) – Surface texture: Profile method – Motif parameters*

BS EN ISO 12179, *Geometrical product specifications (GPS) – Surface texture: Profile method – Calibration of contact (stylus) instruments*

BS EN ISO 13565-1, *Geometric product specifications (GPS) – Surface texture: Profile method – Surfaces having stratified functional properties – Part 1: Filtering and general measurement conditions*

BS EN ISO 13565-2, *Geometric product specifications (GPS) – Surface texture: Profile method – Surfaces having stratified functional properties – Part 2: Height characterization using the linear material ration curve*

BS EN ISO 13565-3, *Geometric product specifications (GPS) – Surface texture: Profile method – Surfaces having stratified functional properties – Part 3: Height characterization using the material probability curve*

3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS EN ISO 3274, BS EN ISO 4287 and BS EN ISO 4288 apply.

4 Surface profile standards

The following standards should be used when measuring and characterizing a surface profile using stylus instruments: BS EN ISO 1302, BS EN ISO 3274, BS EN ISO 4287, BS EN ISO 4288, BS EN ISO 5436-1, BS EN ISO 5436-2, BS EN ISO 11562, BS EN ISO 12085, BS EN ISO 12179, BS EN ISO 13565-1, BS EN ISO 13565-2 and BS EN ISO 13565-3.

BS EN ISO 3274 specifies the characteristics of contact stylus instruments and their metrological characteristics. BS EN ISO 4287 specifies terms and definitions of the surface profile parameters (i.e. the *P*, *W* and *R* parameters, see 5.3) and how to calculate these parameters. BS EN ISO 4288 specifies default values, and basic rules and procedures for surface texture profile analysis. BS EN ISO 11562 specifies the phase correct Gaussian filter that is applied for the various cut-off filters used for surface profile analysis. BS EN ISO 12179 describes methods for calibrating contact stylus instruments for profile measurement and BS EN ISO 5436-1 specifies the artefacts that are used to calibrate stylus instruments. BS EN ISO 5436-2 gives the concepts behind software measurement standards and describes methods for their use. BS EN ISO 1302 specifies the rules for the indication of surface texture in technical product documentation such as drawings, specifications, contracts and reports.

At the time of publication there are no standards that relate to the measurement of surface profile using optical measuring instruments. However, in many cases where a profile can be mathematically extracted from an areal optical scan, the profile characterization and analysis standards can be applied (see BS EN ISO 4287).

There are no methods specified in these BS EN ISO standards regarding how to remove form prior to surface texture analysis. The most common

form removal filter is the linear least squares method and this method is applied to some commercial measuring instruments as a default. The linear least squares method might be the most appropriate in a large range of cases (especially where low slope angle tilt needs to be removed) but it can sometimes lead to significant errors. For example, a linear least squares form removal process introduces tilt into a sinusoidal surface with few periods within the sampling length. Least squares can also be calculated using two different methods, which can provide differing results.

BS EN ISO 13565-1, BS EN ISO 13565-2 and BS EN ISO 13565-3 relate to the measurement of surfaces having stratified functional properties. The roughness profile generated using the filter defined in BS EN ISO 11562 contains some undesirable distortions when the measured surface consists of relatively deep valleys beneath a more finely finished plateau with minimal waviness. This type of surface is common, for example, in cylinder liners for internal combustion engines. BS EN ISO 13565-1 provides a method of greatly reducing these distortions, thus enabling the parameters defined in BS EN ISO 13565-2 and BS EN ISO 13565-3 to be used for evaluating these types of surfaces, with minimal influence from these distortions.

BS EN ISO 12085 defines terms and parameters used for determining surface texture by the motif method. The motif method is based on a graphical method for finding and analyzing those motifs that characterize the texture of a surface and allowing roughness and waviness parameters to be determined from the primary profile. It takes the functional requirements of the surface into account and aims to find relationships between peak and valley locations and these requirements. As the method is independent of any traditional profile filter, the resulting parameters are based on the depth and spacing of the motifs.

5 Guide to terminology

5.1 General

5.1.1 Traced profile

This is the trace of the centre of a stylus tip that has an ideal geometrical form (conical, with spherical tip) and nominal dimensions with nominal tracing force, as it traverses the surface within the intersection plane (see Figure 1).

5.1.2 Reference profile

This is the trace on which the probe would report as it is moved with the intersection plane along a perfectly smooth and flat work piece. It arises from the movement caused by an imperfect datum guideway. If the datum were perfectly flat and straight, the reference profile would not affect the total profile.

5.1.3 Total profile

This is the digital form of the profile reported by a measuring instrument, which combines the traced profile and the reference profile. In most measuring instrument systems it is not practicable to

correct for the error introduced by datum imperfections and the total profile is the only available information concerning the traced profile.

5.1.4 Filters and filtering

Filtering plays a fundamental role in surface texture analysis. It is any means (usually digital, but sometimes mechanical) for selecting a range of structure in the total profile that is considered to be important in a particular situation for analysis. It can also be a means of rejecting information considered irrelevant. For example, this can include attempts to reduce the effect of measuring instrument noise and imperfections.

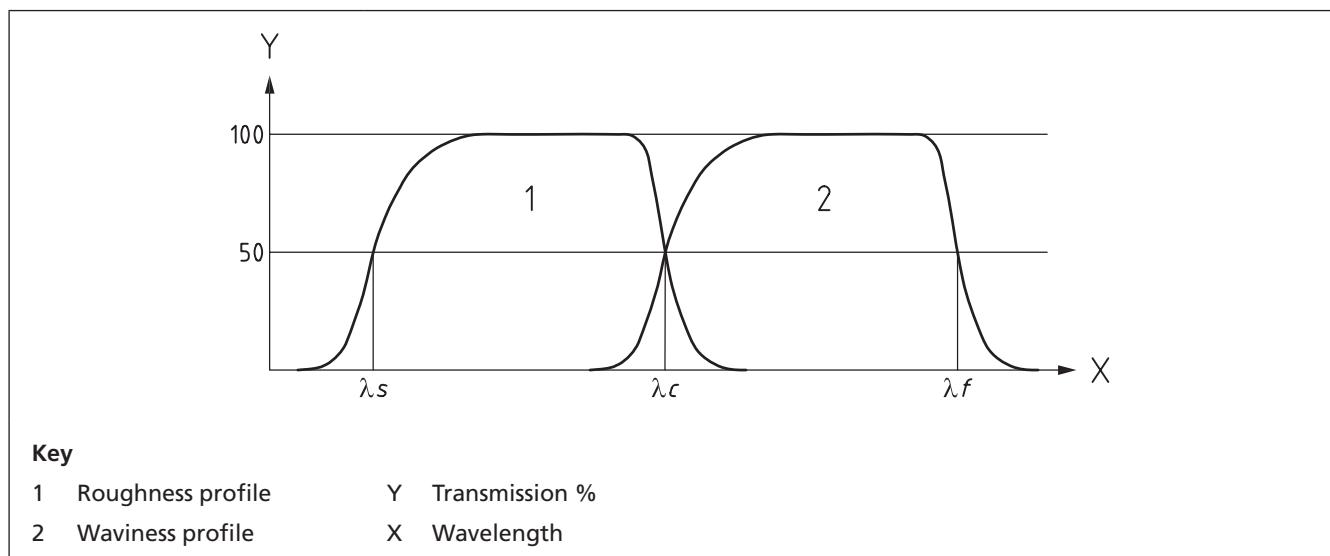
Filters select or reject structure according to its scale in the x axis that is in terms of wavelengths or spatial frequencies (for example as cycles or lines per millimetre). A filter that rejects short wavelengths while retaining longer ones is called a low pass filter since it preserves (or lets pass) the low spatial frequencies. A high pass filter preserves the shorter wavelength features while rejecting longer ones. The combination of a low pass and a high pass filter to select a restricted range of wavelengths, with both high and low regions rejected, is called a band pass filter. The attenuation (or rejection) of a filter should not be too sharp or else differing results can be obtained from surfaces that are almost identical apart from a slight shift in the wavelength of a strong feature. The wavelength at which the transmission (and so also the rejection) is 50% is called the cut-off of that filter, although this use is specific to the field of surface texture.

5.1.5 Profile filters

5.1.5.1 General

The profile filter is defined as the filter that separates profiles into long wave and short wave components. There are three filters used by measuring instruments for measuring roughness, waviness and primary profiles as shown in Figure 4.

Figure 4 Separation of surface texture into roughness, waviness and primary profiles



5.1.5.2 λ_s profile filter

This is the filter that defines where the intersection occurs between the roughness and shorter wavelength components present in a surface (see Figure 4).

5.1.5.3 λ_c profile filter

This is the filter that defines where the intersection occurs between the roughness and waviness components (see Figure 4).

5.1.5.4 λ_f profile filter

This is the filter that defines where the intersection occurs between the waviness and longer wavelength components present in a surface (see Figure 4).

5.1.6 Primary profile

The primary profile is the basis for the evaluation of the primary profile parameters. It is defined as the total profile after application of the short wavelength (low pass) filter, with cut-off λ_s . Ultimately, the finite size of the stylus limits the rejection of very short wavelengths and in practice this mechanical filtering effect is often used by default for the λ_s filter. Since styli vary and since the measuring instrument introduces vibration and other noise into the profile signal that has equivalent wavelengths shorter than the stylus dimensions, λ_s filtration should always be discounted in the total profile. It should be noted that the nominal form is removed before the primary profile is obtained.

5.1.7 Roughness profile

This is defined as the profile derived from the primary profile by suppressing the long wave component using a long wavelength (high pass) filter, with cut-off λ_c . The roughness profile is the basis for the evaluation of the roughness profile parameters. Such evaluation automatically includes the use of the λ_s profile filter, since it derives from the primary profile.

5.1.8 Waviness profile

This is the profile derived by the application of a band pass filter to select the surface structure at longer wavelengths than the roughness. Filter λ_f suppresses the long wave component (profile component) and filter λ_c suppresses the short wave component (roughness component). The waviness profile is the basis for the evaluation of the waviness profile parameters.

5.1.9 Total traverse length

This is the total length of surface traversed in making a measurement. It is usually greater than the evaluation length in order to allow for a short over travel at the start and end of the measurement which can be excluded. This removes mechanical and electrical transients from the measurement and also removes the effects of edges on the filters.

5.1.10 Mean line for the waviness profile

The mean line for the waviness profile is a reference line for parameter calculation. It is the line corresponding to the long wave profile component suppressed by the profile filter λ_f .

5.1.11 Mean line for the primary profile

The mean line for the primary profile is a reference line for parameter calculation. It is the line determined by fitting a least-squares line of nominal form through the primary profile.

5.2 Geometrical parameters

5.2.1 General

The parameters given in 5.2.2 to 5.2.10 are calculated once the form has been removed from the measurement data. Not all of the parameters are useful in all circumstances. The user should select the appropriate parameters for the relevant application. In some circumstances, for example when a parameter is specified on an engineering drawing, the stylus instrument user cannot select the parameters used. The user should obtain information regarding how a parameter is calculated and what it means.

Peaks and valleys are important for evaluating surfaces. Unfortunately it is not always easy to decide what should be counted as a peak or a valley. BS EN ISO 4287 introduces the concept of the profile element consisting of a peak and a valley. Associated with the profile element is a discrimination that prevents small, unreliable measurement features from affecting the detection of elements.

5.2.2 Profile element

This is a section of a profile from the point at which it crosses the mean line to the point at which it next crosses the mean line in the same direction (for example, from below to above the mean line).

5.2.3 Profile peak

This is the part of a profile element that is above the mean line, i.e. the profile from when it crosses the mean line in the positive direction until it next crosses the mean line in the negative direction.

5.2.4 Profile valley

This is the part of a profile element that is below the mean line, i.e. the profile from when it crosses the mean line in the negative direction until it next crosses the mean line in the positive direction.

5.2.5 Discrimination level

A profile could have a slight fluctuation that takes it across the mean line and almost immediately back again. Such fluctuations are not considered to be real profile peaks or real profile valleys. To prevent automatic systems from counting such features, only features larger than a specified height and width are counted. Where there is no specified height and no specified width, a profile peak or profile valley is only considered to be valid if its height exceeds 10% of the R_z , W_z or P_z parameter value and its width exceeds 1% of the sampling length. However, it is essential that both criteria are met simultaneously.

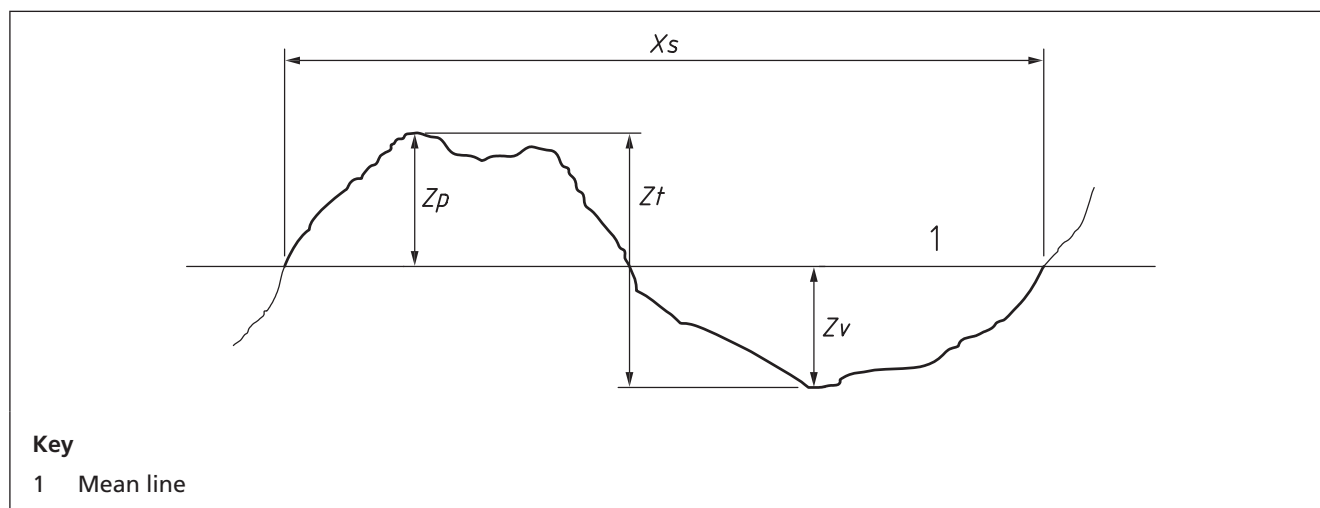
5.2.6 Ordinate value $Z(x)$

This is the height of the assessed profile at any position x . The height is regarded as negative where the ordinate lies below the x axis and positive where the ordinate lies above it.

5.2.7 Profile peak height Z_p

This is the distance between the mean line on the x axis and the highest point of the highest profile peak as shown in Figure 5.

Figure 5 Profile elements



5.2.8 Profile valley depth Z_v

This is the distance between the mean line on the x axis and the lowest point of the lowest profile valley.

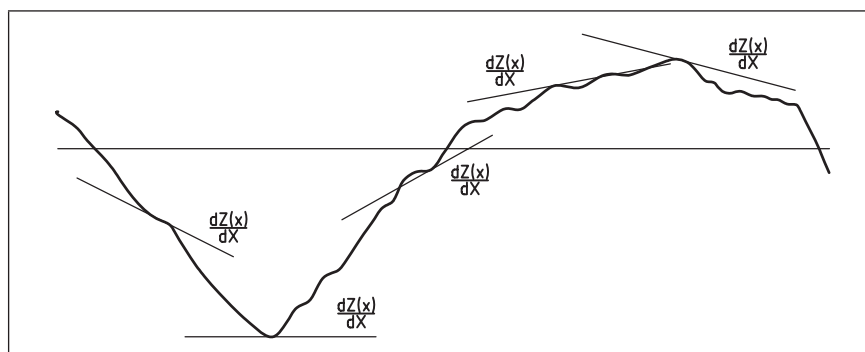
5.2.9 Profile element height Z_t

This is the distance between the lowest point of the lowest profile valley and the highest point of the highest profile peak.

5.2.10 Local slope dZ/dX

This is the slope of the assessed profile at position x_i , as shown in Figure 6. The numerical value of the local slope, and therefore the parameters $P\Delta q$, $R\Delta q$ and $W\Delta q$, depend on the ordinate spacing.

Figure 6 Local slope



5.3 Surface profile parameters

5.3.1 General

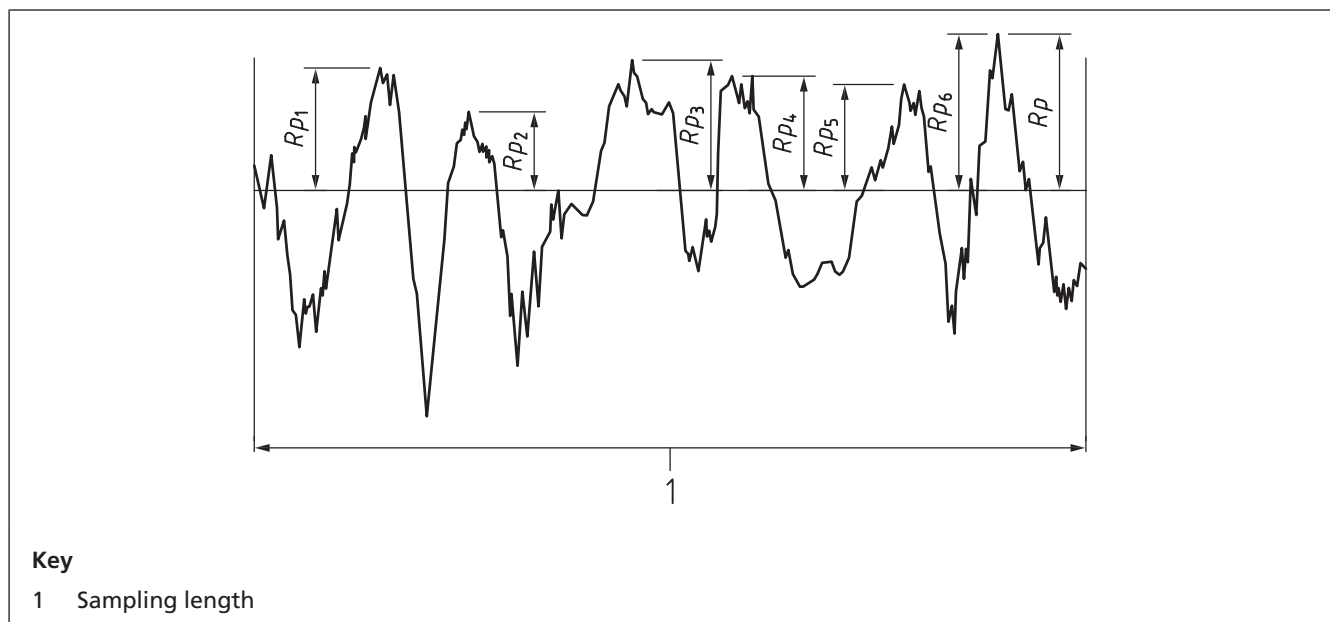
The parameters given in 5.3.2 to 5.3.10 can be calculated from any profile. The first capital letter in the parameter symbol designates the type of profile under evaluation. For example, R_a is calculated from the roughness profile, W_a from the waviness profile and P_a from the primary profile. Though only R parameters are used as examples, the equations also apply to the P and W parameters.

5.3.2 Amplitude parameters (peak to valley)

5.3.2.1 Maximum profile peak height P_p , R_p , W_p

This parameter is the largest profile peak height (R_p) within the sampling length (as shown in Figure 7). This measure is the height of the highest point of the profile from the mean line. The parameter is not often required in preference to parameters based on the total peak-to-valley height. It is often referred to as an extreme-value parameter and as such can be unrepresentative of the surface due to the variation in the numerical value from sample to sample. Several consecutive sampling lengths can be averaged to reduce the variation, but the value is likely to remain too high to be representative of the surface profile. However, this parameter is useful for finding unusual conditions such as a sharp spike or burr on the surface or the presence of cracks and scratches that can indicate a low quality material or low quality processing.

Figure 7 Maximum profile peak height, example of roughness profile

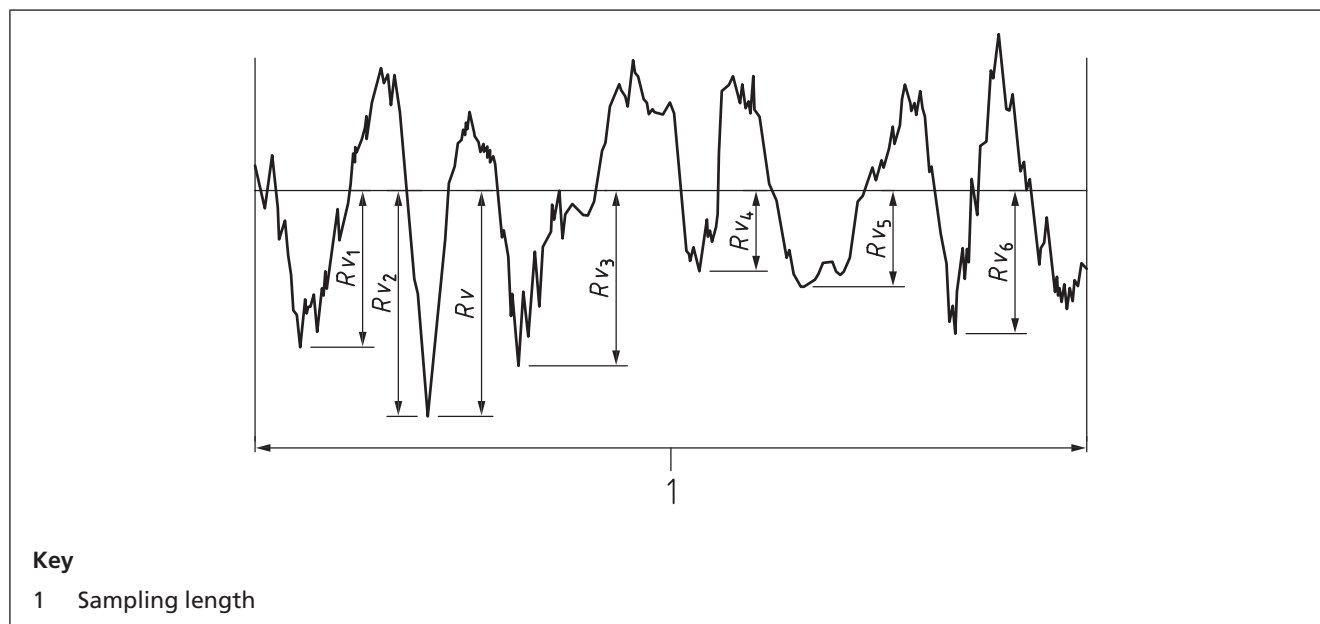


5.3.2.2 Maximum profile valley depth P_v , R_v , W_v

This is the largest profile valley depth (R_v) within the sampling length (see Figure 8). This parameter is the absolute value of the minimum value of the profile deviations from the mean line. It is the depth of the lowest point on the profile from the mean line and again is an

extreme-value parameter. R_v , like R_p , is an extreme parameter and is useful for the detection of cracks, burrs and spikes on the surface.

Figure 8 Maximum profile valley depth, example of roughness profile



5.3.2.3 Maximum height of profile P_z , R_z , W_z

This is the sum of the height of the largest profile peak height (R_p) and the largest profile valley depth (R_v) within a sampling length. R_z does not provide much useful information by itself and is often split into R_p , the height of the highest peak above the mean line, and R_v , the depth of the lowest valley below the mean line. In ISO 4287:1984 the R_z symbol indicated the ten point height of irregularities. Some surface texture measuring instruments measure the former R_z parameter, so care should be taken to avoid ambiguity.

5.3.3 Amplitude parameters (average of ordinates)

5.3.3.1 Arithmetical mean deviation of the assessed profile P_a , R_a , W_a

This is the arithmetic mean of the absolute ordinate values Z_i within the sampling length. The R_a of a surface can vary considerably without affecting the performance of the surface. Therefore, a tolerance band or a maximum R_a value that is acceptable should be specified on the drawing.

This is expressed mathematically as:

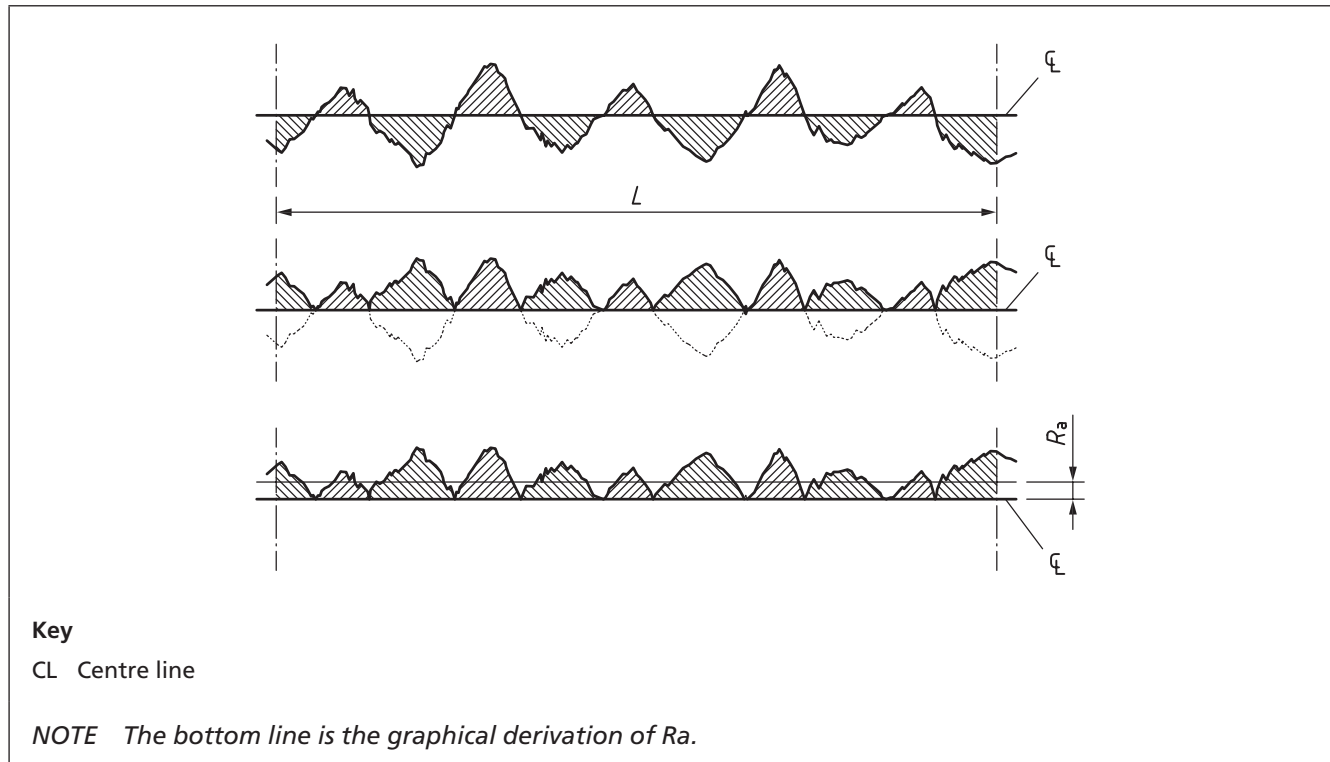
$$R_a = \frac{1}{n} \sum_{i=1}^n |Z_i| \quad (1)$$

where:

- n is the number of measured points in a sampling length (see Figure 10);
- Z_i are the ordinate values within the sampling length;
- i is the measurement point number.

The derivation of this parameter can be illustrated graphically as shown in Figure 9. The areas of the graph below the centre line within the sampling length are placed above the centre line. The R_a value is the mean height of the resulting profile.

Figure 9 Derivation of the arithmetical mean deviation



The R_a value over one sampling length is the average roughness. Therefore, the effect of a single non-typical peak or valley has only a slight influence on the value. Assessments of R_a should be made over a number of consecutive sampling lengths and the average of the values obtained should be accepted. This is to ensure that R_a is typical of the surface under inspection. Measurements should be taken that are perpendicular to the lay. The R_a value does not provide any information regarding the shape of the irregularities on the surface. It is possible to obtain similar R_a values for surfaces having very different profiles and it is useful to quote the machining process used to produce the surface. While R_a is probably the most common of all of the surface texture parameters, users should still consider other parameters that might provide more information regarding the functionality of a surface.

5.3.4 Root mean square deviation from the assessed profile P_q , R_q , W_q

This is the root mean square value of the ordinate values Z_i within the sampling length, or the root mean square of the departures from the mean line of the profile.