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Assessment of surface texture – Guidance and general information

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Contents

Annexes

List of figures

List of tables

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 52, an inside back cover and a back cover.

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This British Standard supersedes BS 1134-1:1988 and BS 1134-2:1990, which are withdrawn.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

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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.

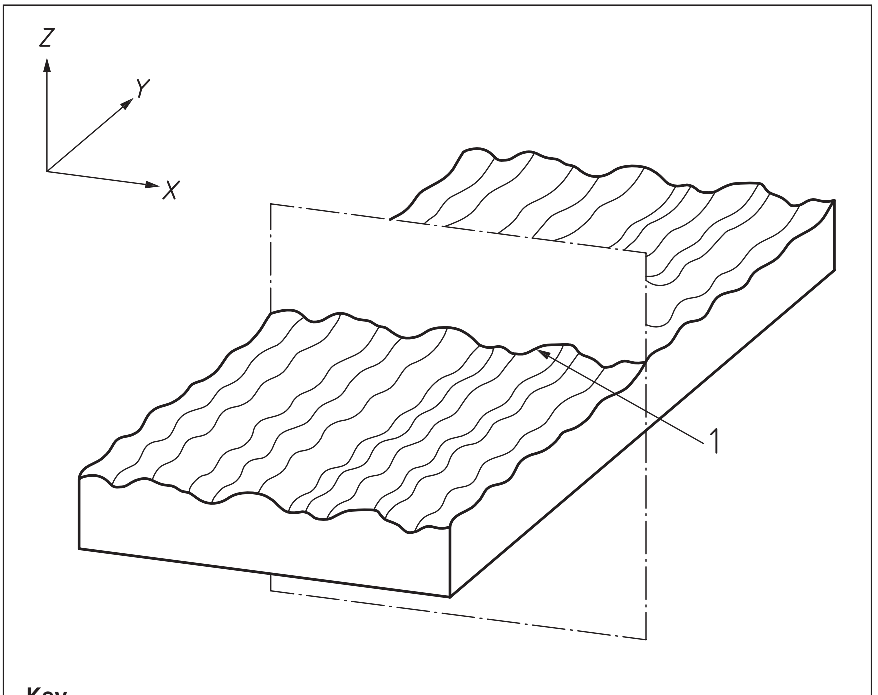
The useful life of a product is governed by the rate of wear of its component parts. The rate of this wear depends on the surface area with which it is in contact and the characteristics of the materials. A rough surface with large peaks has less contact area and wears at a quicker rate than a surface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

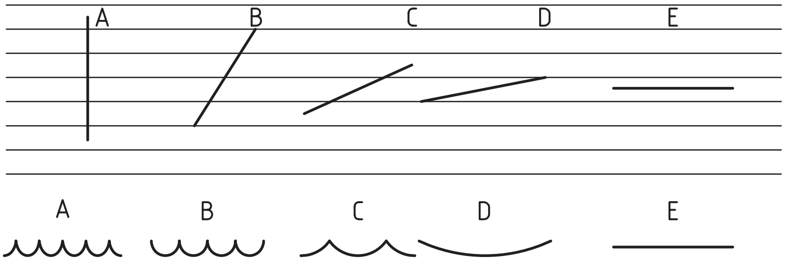


Key

1 Surface profile

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.

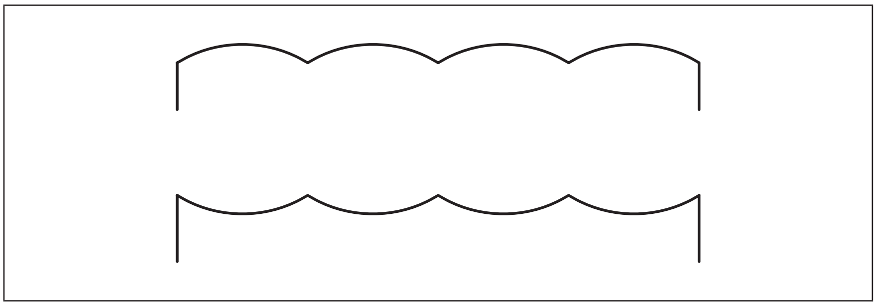
Figure 2 **The effect of measuring in different directions to the surface lay**



NOTE The direction of lay runs across the page.

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 *Ra* 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 *Ra* 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*

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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 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.

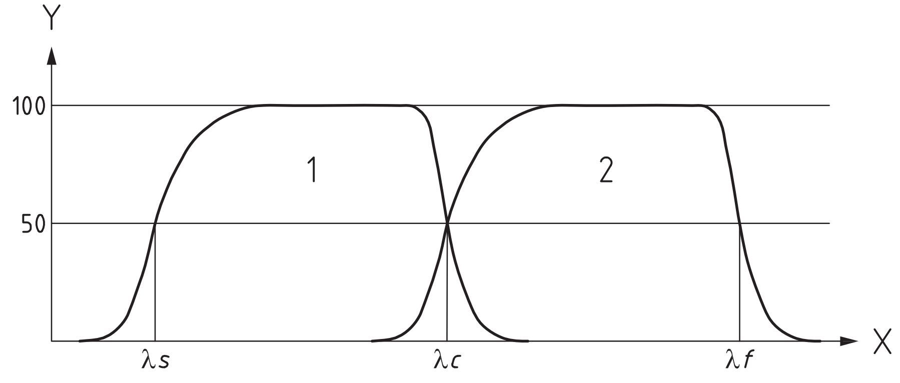
Filters select or reject structure according to its scale in the x axis that is in terms of wavelengths or spatial frequencies (for example as cycles or lines per millimetre). A filter that rejects short wavelengths while retaining longer ones is called a low pass filter since it preserves (or lets pass) 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**



Key

1	Roughness profile	Y	Transmission %
2	Waviness profile	X	Wavelength

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 λs. 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 λs 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, λs 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 λc. The roughness profile is the basis for the evaluation of the roughness profile parameters. Such evaluation automatically includes the use of the λs 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 λf suppresses the long wave component (profile component) and filter λc 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 λf.

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 above 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 Rz, Wz or Pz parameter value and its width exceeds 1% of the sampling length. However, it is essential that both criteria are met simultaneously.

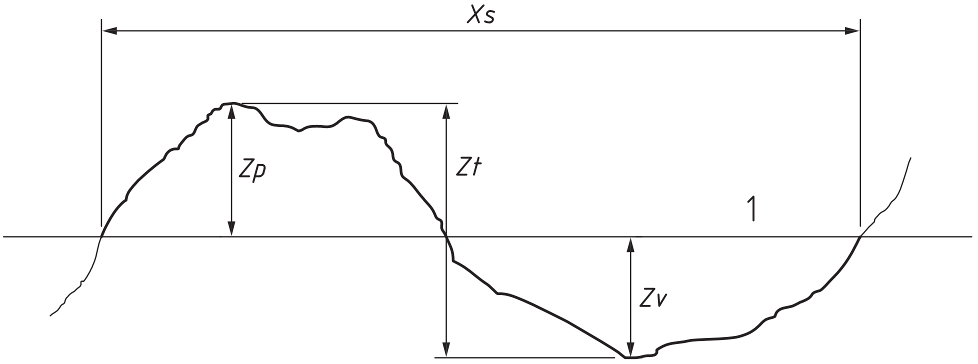
5.2.6 Ordinate value *Z*(x)

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 *Zp*

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**



Key

1 Mean line

5.2.8 Profile valley depth *Zv*

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

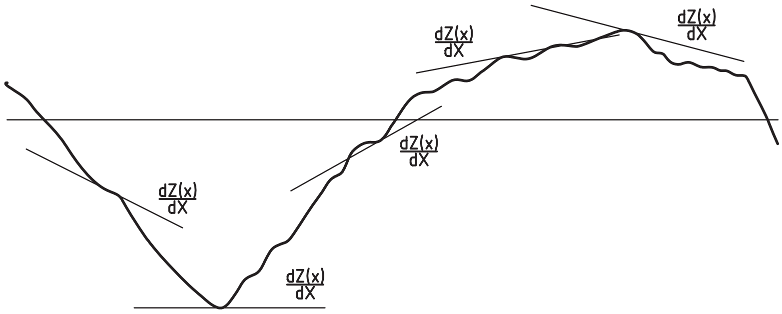
5.2.9 Profile element height *Zt*

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*Δ*q*, *R*Δ*q* and *W*Δ*q*, depend on the ordinate spacing.

Figure 6 **Local slope**



5.3 Surface profile parameters

5.3.1 General

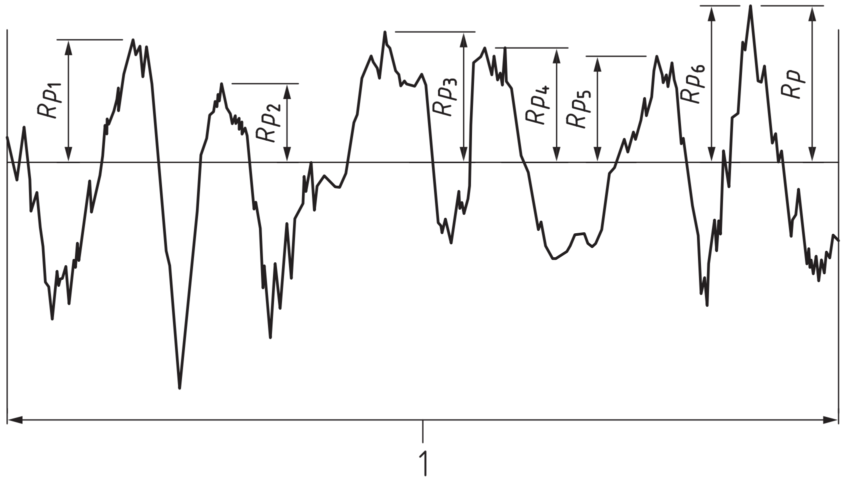
The parameters given in **5.3.2** to **5.3.10** can be calculated from any profile. The first capital letter in the parameter symbol designates the type of profile under evaluation. For example, *Ra* is calculated from the roughness profile, *Wa* from the waviness profile and *Pa* from the primary profile. 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 *Pp*, *Rp*, *Wp*

This parameter is the largest profile peak height (*Rp*) 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**



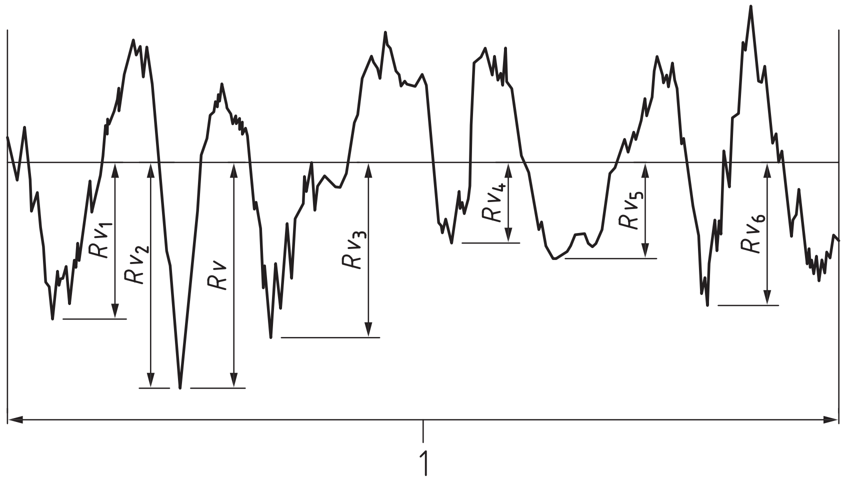
Key

1 Sampling length

5.3.2.2 Maximum profile valley depth *Pv*, *Rv*, *Wv*

This is the largest profile valley depth (*Rv*) 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. *Rv*, like *Rp*, 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**



Key

1 Sampling length

5.3.2.3 Maximum height of profile *Pz*, *Rz*, *Wz*

This is the sum of the height of the largest profile peak height (*Rp*) and the largest profile valley depth (*Rv*) within a sampling length. *Rz* does not provide much useful information by itself and is often split into *Rp*, the height of the highest peak above the mean line, and *Rv*, the depth of the lowest valley below the mean line. In ISO 4287:1984 the *Rz* symbol indicated the ten point height of irregularities. Some surface texture measuring instruments measure the former *Rz* 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 *Pa, Ra, Wa*

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

This is expressed mathematically as:

$$Ra = \frac{1}{n}\sum_{i=1}^{n}\left|Z_i\right| \tag{1}$$

where:

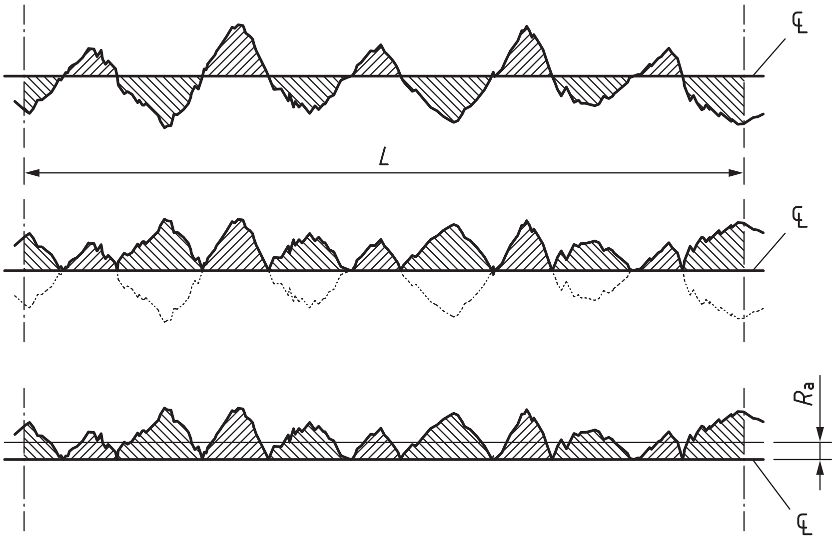
n is the number of measured points in a sampling length (see Figure 10);

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 *Ra* value is the mean height of the resulting profile.

Figure 9 **Derivation of the arithmetical mean deviation**



Key

CL Centre line

NOTE The bottom line is the graphical derivation of Ra.

The *Ra* 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 *Ra* 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 *Ra* is typical of the surface under inspection. Measurements should be taken that are perpendicular to the lay. The *Ra* value does not provide any information regarding the shape of the irregularities on the surface. It is possible to obtain similar *Ra* values for surfaces having very different profiles and it is useful to quote the machining process used to produce the surface. While *Ra* 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 *Pq*, *Rq*, *Wq*

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.

Expressed mathematically, the root mean square, *Rq* is:

$$Rq = \sqrt{\frac{1}{n}\sum_{i=1}^{n} Z_i^2} \tag{2}$$

where:

n is the number of measured points in a sampling length (see Figure 10);

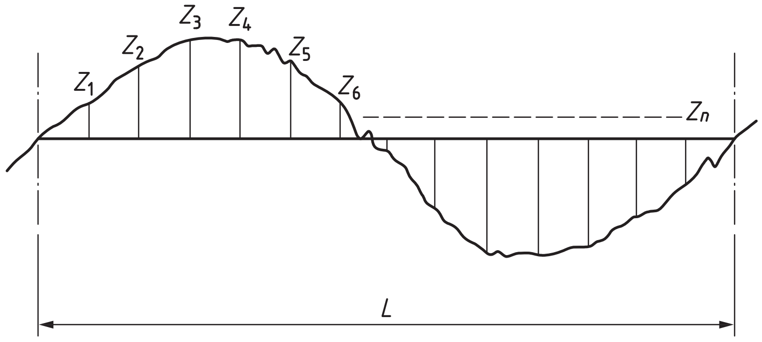
Z_i are the ordinate values within the sampling length;

i is the measurement point number.

When compared to the arithmetic average, the root mean square parameter has the effect of giving extra weight to the numerically higher values of surface height.

Figure 10 illustrates how *Ra* and *Rq* are determined from the profile.

Figure 10 **Determination of *Ra* and *Rq***



Mathematical derivation of *Ra* and *Rq*:

$$Ra = \frac{|Z_1| + |Z_2| \ldots + |Z_n|}{n}$$

$$Rq = \sqrt{\frac{Z_1^{\,2} + Z_2^{\,2} + Z_3^{\,2} \ldots\ldots Z_n^{\,2}}{n}}$$

As *Ra* is easier to determine graphically from a recording of the profile than *Rq*, it was adopted in industry before automatic surface texture measuring instruments became widely available. When roughness parameters are determined instrumentally, *Rq* has the advantage that phase effects from electrical filters can be disregarded. The *Ra* parameter, using the arithmetic average, is affected by phase effects that cannot be ignored. *Ra* has almost superseded *Rq* on machining specifications. However, *Rq* still has value in optical applications where it is directly related to the optical quality of a surface.

5.3.5 Skewness of the assessed profile *Psk, Rsk, Wsk*

This is the quotient of the mean cube value of the ordinate values Z_i and the cube of *Pq*, *Rq* or *Wq* respectively within the sampling length (see Figure 11). The skewness is derived from the amplitude distribution curve; it is the measure of the profile symmetry about the mean line. This parameter cannot distinguish whether the profile spikes are evenly distributed above or below the line and is strongly influenced by isolated peaks or isolated valleys.

Skewness is expressed mathematically as:

$$Rsk = \frac{1}{Rq^3}\left[\frac{1}{n}\sum_{i=1}^{n} Z_i^{\,3}\right] \qquad (3)$$

where:

Rq is the root mean square deviation from the roughness profile;

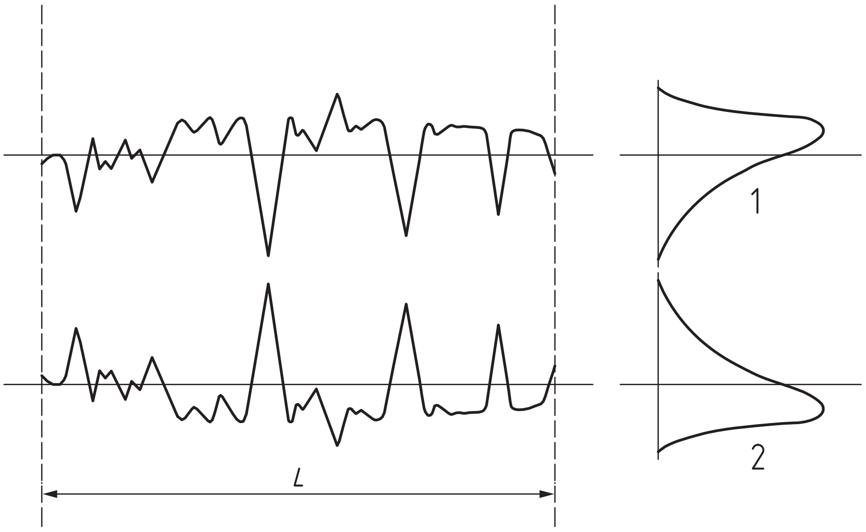
n is the number of measured points in a sampling length (see Figure 10);

Z_i are the ordinate values within the sampling length;

i is the measurement point number.

This parameter represents the degree of bias, either in the upward or downward direction of an amplitude distribution curve. The shape of the curve can provide much information. A symmetrical profile gives an amplitude distribution curve, which is symmetrical either side of the centre line. An unsymmetrical profile results in a skewed curve. The direction of the skew is dependent on whether the bulk of the material is above the mean line (negative skew) or below the mean line (positive skew). Use of this parameter can distinguish between two profiles having the same *Ra* value.

Figure 11 **The difference between positive and negative skewness**



Key

1 *Rsk* is negative

2 *Rsk* is positive

As an example, a porous, sintered or cast iron surface has a large value of skewness. One characteristic of a good bearing surface is that it has a negative skew, indicating the presence of comparatively few spikes that could wear away quickly and relative deep valleys to retain oil traces. A surface with a positive skew is likely to have poor oil retention because of the lack of deep valleys in which to retain oil traces. Surfaces with a positive skewness, such as turned surfaces, have high spikes that protrude above the mean line. *Rsk* correlates well with load carrying ability and porosity.

5.3.6 Kurtosis of the assessed profile *Pku, Rku, Wku*

This is the quotient of the mean quartic value of the ordinate values Z_i and the fourth power of *Pq*, *Rq* or *Wq* respectively, within the sampling length. Unlike *Psk*, *Rsk* or *Wsk*, this parameter cannot only detect whether the profile spikes are evenly distributed but also provides the measure of the sharpness of the profile. A spiky surface has a high kurtosis value and a bumpy surface has a low kurtosis value. This is a useful parameter for predicting component performance with respect to wear and lubrication retention. However, using the kurtosis parameter, it is not possible to distinguish between a peak and a valley.

Kurtosis is expressed mathematically as:

$$Rku = \frac{1}{Rq^4}\left[\frac{1}{n}\sum_{i=1}^{n} Z_i^{\,4}\right] \qquad (4)$$

where:

Rq is the root mean square deviation from the roughness profile;

n is the number of measured points in a sampling length (see Figure 10);

Z_i are the ordinate values within the sampling length;

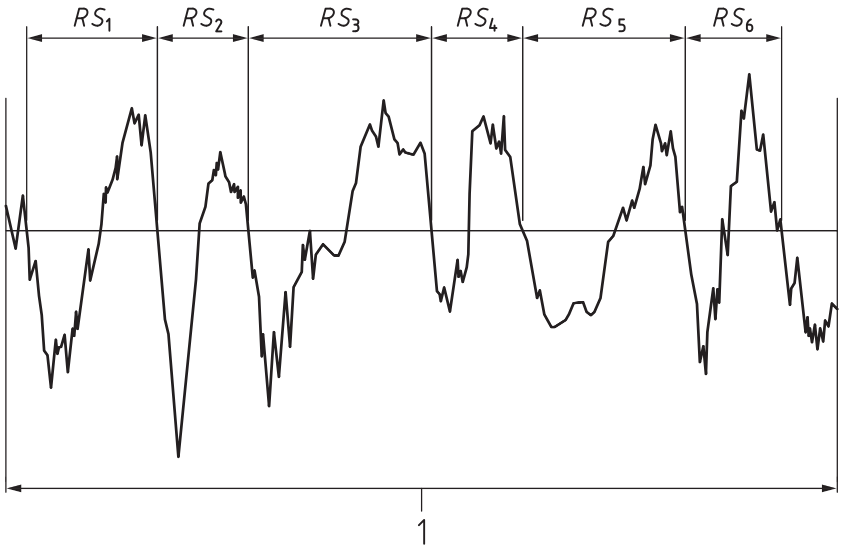
i is the measurement point number.

5.3.7 Spacing parameter

5.3.7.1 Mean width of the profile elements *PSm, RSm, WSm*

This parameter is the mean value of the profile element widths (*Xs*) within a sampling length (see Figure 12). It is the average value of the length of the mean line section containing a profile peak and adjacent valley. This parameter requires height and spacing discrimination. Where these values are not specified then the default height discrimination to be used is 10% of *Pz*, *Rz* or *Wz* respectively and the default spacing discrimination to be used is 1% of the sampling length.

Figure 12 **Width of profile elements**



Key

1 Sampling length

5.3.8 Hybrid parameter

5.3.8.1 Root mean square slope of the assessed profile *P∆q, R∆q, W∆q*

This is the root mean square value of the ordinate slopes d*Z*/d*X* within the sampling length. This parameter depends on both amplitude and spacing and is, therefore, a hybrid parameter. The slope of the profile is the angle it makes with a line parallel to the mean line. The mean of the slopes at all points in the profile within the sampling length is known as the average slope. One example of its use is to determine the developed or actual profile length (i.e. the length occupied if all the peaks and valleys were stretched into a single straight line). The steeper the average slope, the longer the actual length of the surface is. This parameter is used in painting and plating operations where the length of surface for keying is important. Average slope can be related to hardness, elasticity and crushability of the surface. Where the value is small, the indication is that the surface is a good optical reflector.

5.3.9 Curves and related parameters

5.3.9.1 General

Curves and related parameters are defined over the evaluation length rather than the sampling length.

5.3.9.2 Material ratio of the profile *Pmr(c), Rmr(c), Wmr(c)*

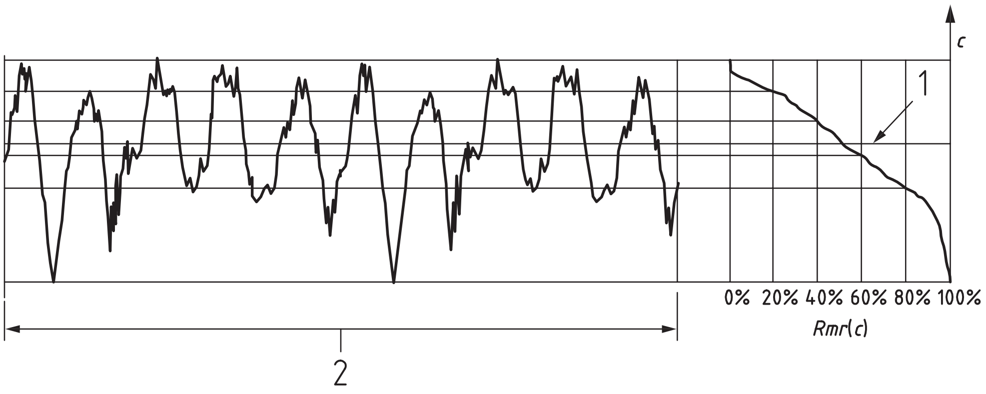
The material ratio of the profile is the ratio of the bearing length to the evaluation length. It is represented as a percentage. The bearing length is the sum of the section lengths obtained by cutting the profile with a line (slice level) drawn parallel to the mean line at a given level. The ratio is assumed to be 0% if the slice level is at the highest peak, and 100% if it is at the deepest valley. Parameter *Pmr*(*c*), *Rmr*(*c*), *Wmr*(*c*) determines the percentage of each bearing length ratio of a single slice level or nineteen slice levels which are drawn at equal intervals within *Pt*, *Rt* or *Wt* respectively.

5.3.9.3 Material ratio curve of the profile

This is the curve representing the material ratio of the profile as a function of level. By plotting the bearing ratio at a range of depths in the profile, the way in which the bearing ratio varies with depth can easily be seen and provides a means of distinguishing between different shapes on the profile. The definition of the bearing area fraction is the sum of the lengths of individual plateaux at a particular height, normalized by the total assessment length, and is the parameter designated *Rmr* (see Figure 13). Values of *Rmr* are sometimes specified on drawings. However, this can lead to large uncertainties if the bearing area curve is referred to the highest and lowest points on the profile.

Many mating surfaces requiring tribological functions are usually produced with a sequence of machining operations. Usually the first operation establishes the general shape of the surface with a relatively coarse finish and further operations refine this finish to produce the properties required by the design. This sequence of operations removes the peaks of the original process but the deep valleys are left untouched. This process leads to a type of surface texture that is referred to as a stratified surface. The height distributions are negatively skewed, therefore making it difficult for a single average parameter such as *Ra* to represent the surface effectively for specification and quality control purposes.

Figure 13 **Material ratio curve**



Key

1 Mean line

2 Evaluation length

5.3.9.4 Profile section height difference *Pδc, Rδc, Wδc*

This is the vertical distance between two section levels of given material ratio.

5.3.9.5 Relative material ratio *Pmr, Rmr, Wmr*

This is the material ratio determined at a profile section level *Rδc*, and related to a reference *C*0.

Where:

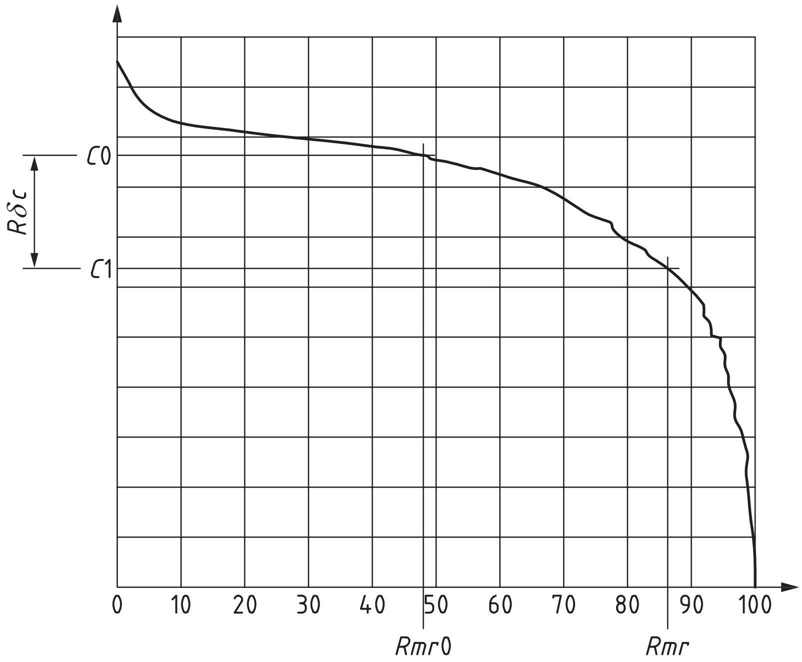
$$C1 = C0 - R\delta c \text{ (or } P\delta c\text{, or } W\delta c\text{)} \tag{5}$$

and:

$$C0 = C\,(Pmr0,\ Rmr0,\ Wmr0) \tag{6}$$

Rmr refers to the bearing ratio at a specified height (see Figure 14). One way of specifying the height is to move over a certain percentage (the reference percentage) on the bearing ratio curve and then to move down a certain depth (the slice depth). The bearing ratio at the resulting point is *Rmr*. The purpose of the reference percentage is to eliminate spurious peaks from consideration as these peaks tend to wear off in early part use. The slice depth then corresponds to an allowable roughness or to a reasonable amount of wear.

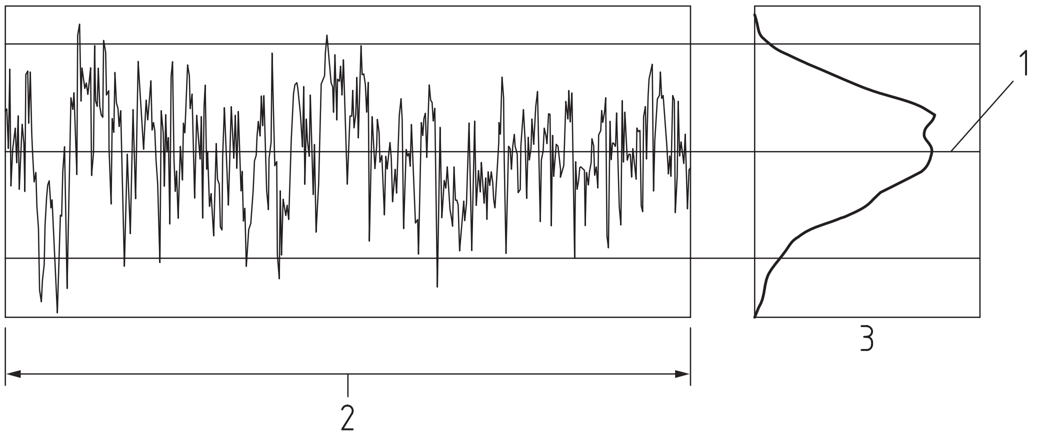
Figure 14 **Profile section level separation**



5.3.9.6 Profile height amplitude curve

This is the sample probability density function of the ordinate *Z*(x) within the evaluation length. The amplitude distribution curve is a probability function that gives the probability that a profile of the surface has a certain height, at a certain position. The curve has the characteristic bell shape of many probability distributions (see Figure 15). The curve tells the user how much of the profile lies at a particular height, in terms of a histogram.

Figure 15 **Profile height amplitude distribution curve**



Key

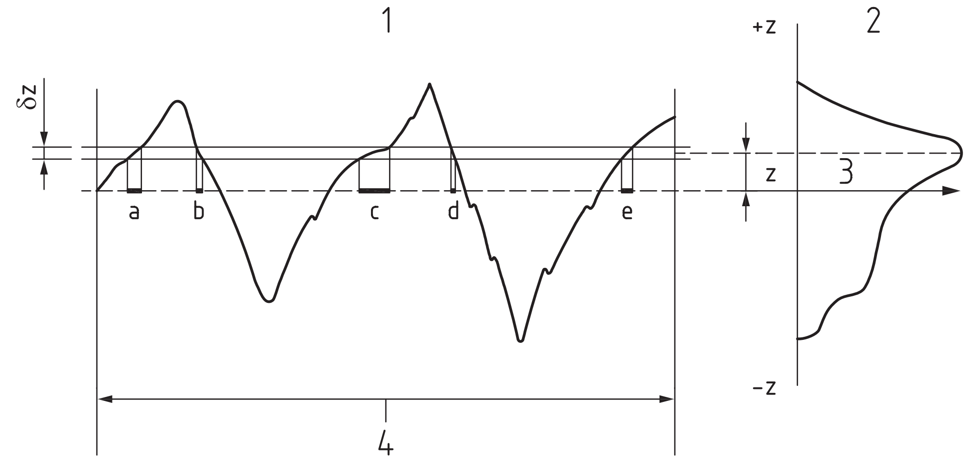
1 Mean line

2 Evaluation length

3 Amplitude density

The profile height amplitude curve illustrates the relative total lengths over which the profile graph attains any selected range of heights above or below the mean line (see Figure 16). The horizontal lengths of the profile included within the narrow band, δz, at a height, z, are, *a*, *b*, *c*, *d* and *e*. By expressing the sum of these lengths as a percentage of the evaluation length, a measure of the relative amount of the profile at a height, z, can be obtained.

Figure 16 **Amplitude distribution curve**



Key

1	Profile graph
2	Amplitude distribution curve
3	Amplitude density
4	Evaluation length

This graph is termed the amplitude distribution at height, z. By plotting density against height the amplitude density distributed over the whole profile can be seen. This produces the amplitude density distribution curve.

5.3.10 Parameter overview

Recent and out-of date parameters are given in Annex A, Table A.1. Also included is whether the parameter is calculated over a sampling length or over the evaluation length.

6 Results obtained with common production methods and materials

Surface roughness values produced by common production processes and materials are given in Table 1.

Table 1 **Surface roughness values produced by common production processes and materials**

Process	**Roughness values** *Ra*/µm												
	50	**25**	**12.5**	**6.3**	**3.2**	**1.6**	**0.8**	**0.4**	**0.2**	**0.1**	**0.05**	**0.025**	**0.0125**
Laser machining						■	■	■	■	■	■	■	
Flame cutting	■	■	■										
Snagging	■	■	■	■									
Sawing	■	■	■	■	■								
Planing, shaping	■	■	■	■	■	■	■						
Drilling			■	■	■	■							
Chemical milling			■	■	■	■							
Electro-discharge machining		▐	■	■	■	■	■	■	■	■			
Milling	■	■	■	■	■	■	■	■					
Broaching				■	■	■	■						
Reaming				■	■	■	■	■					
Boring, turning		■	■	■	■	■	■	■	■	■			
Barrel finishing					■	■	■	■	■	■			
Electrolytic grinding							■	■	■				
Roller burnishing							■	■	■				
Grinding				■	■	■	■	■	■	■	■		
Honing						■	■	■	■	■	■		
Polishing							■	■	■	■	■	■	
Lapping							■	■	■	■	■	■	
Superfinishing							■	■	■	■	■	■	
Sandcasting	■	■	■										
Hot rolling	■	■	■										
Forging		■	■	■	■								
Permanent mould casting				■	■	■							
Investment casting				■	■	■	■						
Extruding			■	■	■	■	■						
Cold rolling, drawing				■	■	■	■	■					
Die casting					■	■	■						

NOTE The ranges shown above are typical of the processes listed. Higher or lower values can be obtained under special conditions.

7 Stylus instruments

7.1 A typical stylus instrument

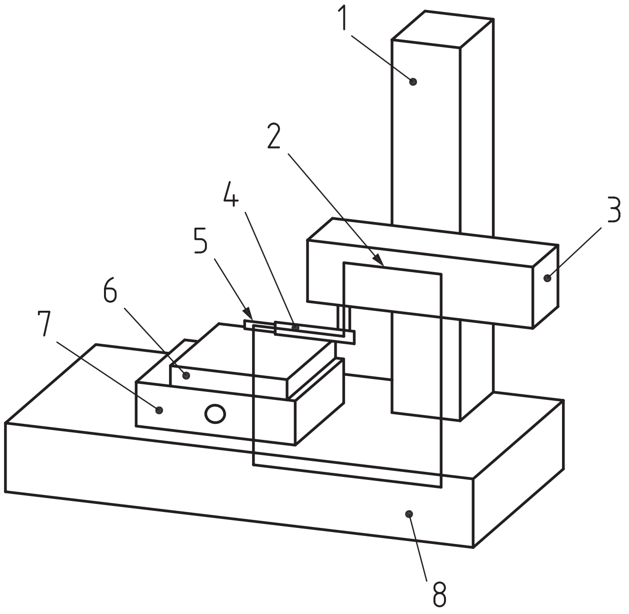
A typical stylus instrument consists of a stylus that makes physical contact with and moves across the surface being measured, and a transducer to convert its vertical movement into an electrical signal. Other components are shown in Figure 17 and include: a pickup, driven by a motor and gearbox, which draws the stylus over the surface at a constant speed; an electronic amplifier to boost the signal from the stylus transducer to a useful level; and a device, also driven at a constant speed, for recording the amplified signal or a computer that automates the data collection.

NOTE Definitions of the different elements of a typical stylus instrument are given in BS EN ISO 3274.

The part of the stylus in contact with the surface is usually a diamond tip with a carefully manufactured profile. Owing to their finite shape, some styli on some surfaces do not penetrate into valleys and give a distorted or filtered measure of the surface texture. Consequently, certain parameters are more affected by the stylus shape than others. The effect of the stylus forces can affect the measurement results. Where a force is too high it can cause damage to the surface being measured. Where a force is too low it can prevent the stylus from staying in contact with the surface.

For an accurate cross section of the surface to be measured, the user should check that the stylus follows an accurate reference path as it traverses the surface. The user should check that the reference path has the general profile of, and be parallel to, the nominal surface. Such a datum can be developed by a mechanical slideway.

Figure 17 **Elements of the typical stylus instrument**



Key

1	Column
2	Measurement loop
3	Drive unit
4	Probe (pick up)
5	Stylus
6	Work piece
7	Fixture
8	Base

7.2 Portable stylus instruments

The description of a typical stylus instrument in **7.1** refers mainly to a tabletop measuring instrument that is not moved on a regular basis. There are a number of portable measuring instruments that can be mounted directly onto the surface being measured.

Whilst these measuring instruments have a number of obvious advantages, the user should be aware of the following disadvantages and limitations.

a) Manufacturing conditions on the shop floor environment are likely to be uncontrolled, leading to temperature gradients, dust, dirt and vibration. These factors should be taken into account when using results obtained under these conditions.

b) Hand held measuring instruments tend to have fewer measurement parameters available to the user than tabletop measuring instruments.

c) The traverse length can be shorter than that of tabletop measuring instruments.

8 Measurement preparation and measuring instrument set up

8.1 General

A surface texture measuring instrument should be used in a safe and stable environment to obtain the most accurate performance.

8.2 Environmental conditions

The measuring instrument should be used in an environment in which it is not affected by the effects of dust, vibration and direct sunlight.

Environmental conditions should be in accordance with the following.

a) A location should be selected in which the ambient temperature is maintained within 20 °C ±10 °C (with a condensation-free humidity of less than 85% relative humidity).

b) The measuring instrument should be stored in a location where the temperature remains between −10 °C and 60 °C.

c) Mist and dust should be wiped from the work piece surface using a lint free cloth prior to surface measurement.

d) Contamination should be removed from the surface, preferably by blowing the surface with filtered air.

e) Oil or grease should be removed from the surface using a solvent.

8.3 Preparation for measurement

The electrical unit should be switched on at least one hour before any measurements take place. The measuring instrument therefore has time to stabilize (the manufacturer’s instructions should be referred to for the typical stabilization time for the measuring instrument).

The measuring instrument should always be calibrated prior to measurement. Before calibration of the measuring instrument takes place, the stylus should be checked visually for signs of wear or damage.

The user should clean the test specimen using an appropriate cleaning method (this will vary depending upon the material) and check that it is free of dust and dirt. Visual examination of a 2 μm tip stylus or smaller might not be practicable without the aid of specialized instrumentation such as a scanning electron microscope. In some cases chemical cleaning is preferable to the use of lint free cloth. Where the surface texture is coarse, then the cloth might deposit fabric on the surface that could affect the reading.

After measurement of the calibration artefact, the indicated value should be compared to the value associated with the calibration artefact. Where the measured value differs from the value that is shown on the calibration certificate then the measuring instrument should be re-calibrated and adjusted. Depending on the measuring instrument used, this adjustment can be carried out in a number of ways. Some measuring instruments use a simple positive or negative screw adjustment that alters the display value in line with the *Ra* indication on the manufacturer's reference specimen. With measuring instruments that are software or processor based, the sensitivity of the measuring instrument is automatically calibrated by entering the value shown on the calibration certificate into the machine display as prompted.

8.4 Stylus size and shape

8.4.1 General

The stylus is the only active component in contact with the surface being measured (possibly with the exception of a skid). The dimension and shape should be considered when selecting a stylus as it is these features that have an influence on the information gathered during measurement. The ideal stylus shape is a cone with a spherical tip. The spherical type of stylus usually has a cone angle of either 60° or 90° with a typical tip radius of 1 μm, 2 μm, 5 μm and 10 μm. However, truncated pyramidal, or chisel shaped tips, 0.1 μm in radius, can be obtained for specialized measurements.

A stylus radius should be chosen in accordance with Table 2. The static measuring force at the mean position of the stylus should be 0.75 mN, in accordance with BS EN ISO 3274. This should not change during the measurement. The manufacturer of the measuring instrument generally sets this force. Where there is concern about the force value, it is practicable to load the stylus onto a suitable pan-balance. The tip of the stylus is subject to wear and should be checked on a regular basis. A damaged stylus tip can lead to erroneous measurements.

Table 2 **Relationship between the roughness cut-off wavelength λc, tip radius and maximum sampling spacing**

λc /mm	λs /μm	Roughness cut-off wavelength ratio	r_{tip} maximum /μm	Maximum sampling spacing /μm
0.08	2.5	30	2	0.5
0.25	2.5	100	2	0.5
0.80	2.5	300	2	0.5
2.50	8.0	300	5	1.5
8.00	25.0	300	10	5.0

When checking the condition of the stylus the user should record the measuring instrument reading for a chosen surface texture parameter (usually *Ra*) against the value for the calibration artefact stated on its calibration certificate.

Where there is a 10% difference between the previous reading and the newly recorded reading, the user should be alerted to the fact that there might be a potential problem with the stylus which should be examined for signs of wear or damage.

The size of the stylus can affect the accuracy of the traced profile in a number of ways: penetration into valleys, distortion of the peak shape and re-entrant features.

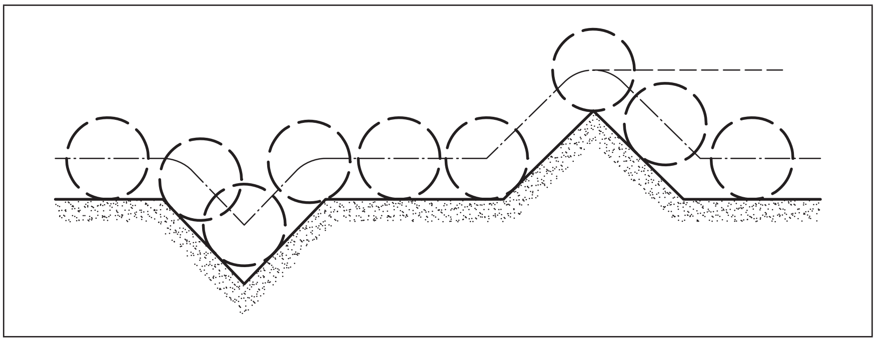
8.4.2 Penetration into valleys

On surfaces with deep, narrow valleys, a spherical stylus might not be able to penetrate fully to the bottom and so should not be selected when measuring surface texture. The larger the tip radius, the less likely it is to be able to penetrate to the bottom of the valleys. This means that the resulting value of a roughness height parameter is lower than the actual value.

8.4.3 Distortion of the peak shape

When a spherical stylus passes over a surface peak, the point of contact on the stylus moves across its tip. The stylus follows a path that is more rounded than the peak. As the stylus is raised to its full height when it makes contact with the crest, the actual peak height is measured (see Figure 18).

Figure 18 **The effects of using a stylus with a spherical tip**



A stylus with a spherical tip causes:

a) the peaks of a profile to become rounded due to the curvature of the stylus tip; and

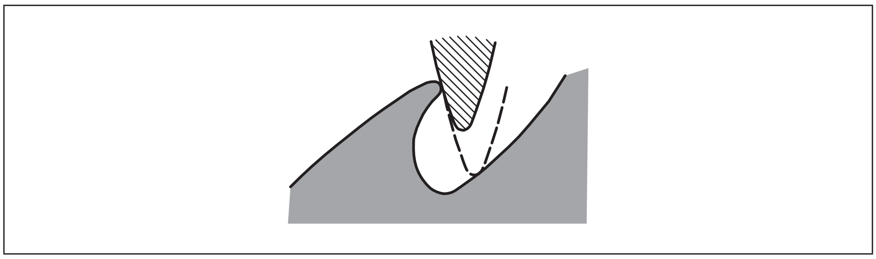
b) the depth of the profile valleys to be reduced.

However, the actual peak height is reported accurately.

8.4.4 Re-entrant features

The stylus detects the surface profile by moving downwards. It cannot detect re-entrant features (as shown in Figure 19) and is, therefore, unable to measure the actual depth of the valley. Instead, it reports a simpler profile as the stylus slides over the feature to make contact with the next peak.

Figure 19 **Example of a stylus tip measuring a re-entrant feature**



8.5 Choice of cut-off wavelength (sampling length) and filters

The decision as to whether the surface being inspected meets the requirements it is being tested against should depend on the following:

a) the number of sampling lengths within the evaluation length;

b) the number of evaluation lengths or measurements taken on the surface;

c) the total number of measurements being taken; and

d) the evaluation length.

The resulting decision is likely to be more accurate with the increase in length of the surface being tested and the increase in the number of surface test lengths.

However, as costs increase with the increase in measurements taken, the inspection process is often a compromise between reliability and cost.

When the sampling length is indicated on a drawing or other documentation then the cut-off wavelength, λc, should be chosen to be equal to this sampling length. The cut-off wavelength is the means by which the resulting profile waveform is made to simulate the effect of restricting the assessment to the sampling length. Table 2 should be referred to for the relationship between cut-off wavelength, tip radius and maximum sampling spacing.

When a component is manufactured from a drawing, the surface texture specification normally includes the sampling length for measuring the surface profile. The most commonly used sampling length is 0.8 mm. However, when no indication is given on the drawing the user requires a means of choosing what value to use. The sampling length should only be selected after considering the magnitude of the surface texture and which characteristics are required for the measurement. A value of 0.8 mm can be used for nearly all of the machined surfaces (see Table 3). However, it might not be suitable for assessing a particular feature of the surface texture and so the function of the surface and the precision of the machining process should be taken into account.

Filtering is the procedure that enables the user to separate certain spatial frequency components of the surface profile. A filter is an electronic, mechanical, optical or mathematical transformation of a profile to remove wavelength components of the surface outside the user's range of interest.

Table 3 **Choice of cut-off wavelength for a number of common machining operations**
Dimensions in millimetres

	Cut-off wavelength				
Process	**0.25**	**0.8**	**2.5**	**8.0**	**25.0**
Milling		✓	✓	✓	
Turning		✓	✓		
Grinding	✓	✓	✓		
Shaping		✓	✓	✓	
Boring		✓	✓	✓	
Planing			✓	✓	✓
Reaming		✓	✓		
Broaching		✓	✓		
Diamond boring	✓	✓			
Diamond turning	✓	✓			
Honing	✓	✓			
Lapping	✓	✓			
Superfinishing	✓	✓			
Buffing	✓	✓			
Polishing	✓	✓			
Shaping		✓	✓	✓	
Electro discharge	✓	✓			
Burnishing		✓	✓		
Drawing		✓	✓		
Extruding		✓	✓		
Moulding		✓	✓		
Electro-polishing		✓	✓		

The spatial frequency of components present in the electrical waveform that represents the surface is dependent on the spacing of irregularities and on the measuring speed of the measuring instrument. For instance, if the irregularity spacing of a surface is 0.01 mm at a measuring speed of 1 mm per second, the frequency returned by the measuring instrument would be 100 Hz. If the irregularity spacing were 0.25 mm at the same measuring speed, the frequency returned would be 4 Hz. If a high pass filter were inserted that suppresses any frequency below 4 Hz, only those irregularities of less that 0.25 mm spacing would be represented in the filtered profile. This condition would provide the measuring instrument with a sampling length of 0.25 mm. By introducing different filters, the sampling length best suited to the surface can be selected. If the same filter were used at a measuring speed of 2 mm per second, the sampling length would be 0.5 mm.

On measuring instruments that have a variable measuring speed, the measuring speed appropriate to the electrical filter used should be selected, in order to obtain the specified cut-off. Various sampling lengths can be obtained with the use of a single filter and in conjunction with the selection of different measuring speeds, but for practical reasons this method it is not often used.

A roughness filter is used when measuring potential characteristics such as friction, wear, reflectivity, resistance to stress failure and lubricating properties. Waviness can be filtered out so that the roughness can be observed in isolation. The roughness profile includes only the shortest wavelengths; the longer wavelengths associated with waviness are attenuated. Roughness is of significant interest in manufacturing as it is often this feature of a surface that defines how it looks, feels and behaves when in contact with another surface.

A waviness filter should be used to determine the effects of machine tool performance and also types of component performance such as noise and vibration by removing profile and roughness.

Filtering can reduce the effect of vibrations without losing essential data and can be used to reduce the need for accurate setting-up when using an independent datum. If the general form of the surface is not parallel to the path of the pick-up, the graph will slope across the chart. The slope is represented by low frequencies in the waveform; if this is filtered out the graph produced will be more or less parallel to the chart co-ordinates.

Typically, modern measuring instruments have a choice of digital filters that can be selected according to the type of measurement required.

Examples include:

a) a phase-corrected, amplitude transmission factor 50%, digital filter;

b) a phase-corrected, amplitude transmission factor 75%, digital filter;

c) a non-phase-corrected, amplitude transmission factor 75%, digital filter; and

d) a phase-corrected, amplitude transmission factor 50%, digital filter.

Ideally, the filter characteristics would change instantaneously at the sampling length selected. All irregularities spaced at less than the sampling length would be passed unchanged, while those greater than the cut-off would be suppressed. However, in practice this is difficult to achieve without great expense, so the filters have been standardized (see BS EN ISO 11562) to give a percentage transmission at the cut-off. Consequently, the amplitudes of the irregularities that have a spacing equal to the cut-off length are reduced by the percentage stated of their actual value. The amplitudes of shorter wavelength irregularities remain unchanged, while those of the longer wavelength are progressively reduced. In normal applications this does not significantly affect the value of a surface texture parameter.

8.6 Choice of measuring speed

The pick-up and transducer convert the movement of the stylus into an electrical signal having a waveform. The closer the irregularities are, the higher the spatial frequency is. The frequency also increases with a faster measuring speed. It is important to consider the relationship between irregularity spacing, measuring speed and signal frequency when measuring surface texture. To obtain an accurate graph of the surface, the frequencies generated need to be accurately transmitted through the system.

A stylus traversing at a measuring speed of 1 mm per second over a surface having peaks regularly spaced at intervals of 0.01 mm would have a resulting frequency of 100 Hz (100 peaks encountered over one second). By halving the measuring speed to 0.5 mm per second the frequency is halved and by increasing the measuring speed to 2 mm per second the frequency doubles. The maximum frequency to be handled can be brought within the bandwidth of the system by selecting an appropriate maximum measuring speed. However, the amplifier frequency response can be modified by the use of a filter. It is therefore possible to separate roughness from waviness.

On many surface texture measuring instruments, the measuring speed is fixed by the manufacturer and the end user has no control over this parameter.

9 Measuring surface texture using comparative methods

9.1 General

Surface texture can also be assessed by indirect means that do not require a stylus instrument but use straightforward sensory comparative methods instead.

Comparative methods assess the surface by means of observation and/or feel of the surface. The subjectivity of those using such methods compromises the accuracy or consistency of the results and this should be taken into account when choosing the best means of assessing the surface texture. However, while comparative methods tend to be less accurate than using a stylus, they are generally cheaper and more convenient than stylus methods.

A typical set of comparison specimens consists of a wallet containing a number of specimens covering example surface textures of various machining operations – turning, milling (horizontal and vertical), grinding, lapping and reaming. The user can compare the machined component with the feel and appearance of the corresponding comparison specimen. The user should check that a comparison block produced by the same production process is used to produce the component that is selected. Comparison artefacts are available for different processes including flat and cylindrical surfaces.

After assessment using a comparison specimen, the surface texture should be given a numerical value. This helps to increase the accuracy of the comparison and reduce the subjectivity of assessment by comparative methods.

9.2 Advantages

The advantages of using comparative methods are that:

a) they are superior to visual examination alone;

b) they do not require skill in setting up and operating an electronic measuring instrument;

c) they are portable; and

d) they can be as straightforward as a fast and simple check.

9.3 Disadvantages

The disadvantages of using comparative methods are that:

a) individuals might obtain different readings for the same component; and

b) practice and skill are required to maintain consistent results.

10 Making measurements and interpreting the results

10.1 General

Where using tabletop machines, the work piece should be located on the measuring instrument base or, where using a portable measuring instrument, it should be located on a suitably flat and stable surface. Where a work piece is heavy enough that it is unlikely to move when measured, it is not necessary to use a constraint to prevent it from moving. However, where a work piece is small, light and likely to move when measured, clamps or a vice should be used. Where clamping forces are used, the user should check that they do not distort the work piece. In some cases, waxes, modelling compounds or double-sided adhesive tape can be used as alternatives to clamps. Restraining materials that are elastic or can deform easily should not be used, as movement might occur during the measuring process.

The work piece should be aligned to the traverse direction of the measuring stylus within the working range of the measuring instrument. With hand held measuring instruments this is carried out by adjusting the level of the drive unit by the use of tilt adjustment knobs. For tabletop machines a levelling table is often used allowing adjustment in the x and y axes. Levelling a work piece for measurement at high magnification can require skill and be time consuming. Auto-levelling tables that allow automatic adjustments to be made quickly and easily can be obtained from some manufacturers. However, auto-levelling also requires some initial levelling to get enough of the scan in range. Using auto-levelling devices require the user to make a preliminary measurement after which the table adjusts without user intervention. Where the machine is software based and contains the appropriate software, adjustment can be mathematically corrected by the tilt compensation function. It should be noted that the measurement of the work piece cannot be carried out where the level of the work piece is not within the measuring instrument range.

The next stage is for the user to select the parameters required for measurement. This depends on the type and manufacture of the measuring instrument and reference should be made to the manufacturer's manual.

At least ten surface measurements should be made, where practicable. Each measurement should be made on a typical surface and measurements should not be made where there are obvious holes, scratches or other machining damage. These can produce anomalies in the readings that can affect the overall surface profile and can be a particular problem when measuring ceramic surfaces.

The measurement traverse can then be made. On computer based measuring instruments, it is sometimes possible to apply files and parameters to a profile after it has been measured. However, the user should still consider applying them before taking measurements in order to obtain a suitable measurement length, speed, etc. On completion of the measurement the results are output in various forms depending on the make and manufacturer of the measuring instrument. They usually take the form of a trace, a printout of results or a file held in computer memory.

By visual examination of the work piece it can be seen whether the surface texture is markedly different over various areas or homogeneous over the whole. Surface texture parameters are not useful for the description of surface defects such as scratches and pores and such structures should not be considered during surface texture inspection. Where the surface is homogeneous, then parameter values taken from anywhere on the surface can be used for comparison with requirements specified on drawings or specification documents. Where the surface texture is markedly different over the work piece then parameter values determined over each area should be used separately for comparison. For stated requirements that specify the upper limit of the parameter, the areas of the surface that indicate maximum values should be used for comparison.

10.2 The 16% rule

Where the requirements specify the upper limit of a parameter, the surface is considered acceptable if not more than 16% of all the measured values (based on the evaluation length) exceed the value specified on the drawing. This rule should only be applied when the measurements are distributed over a representative area of the surface.

Conversely, for requirements specifying the lower limit of a parameter, the surface is considered acceptable if not more than 16% of all measured values (based on the evaluation length) are less than the value specified on the drawing.

10.3 The maximum (“max”) value rule

10.3.1 General

Where the requirements specify the maximum value of a parameter, none of the measured values of the parameter over the entire surface can exceed the value specified. To designate the maximum permissible value of the parameter, the “max” index has to be added to the parameter symbol, for example, *Rz*max.

10.3.2 Selecting a cut-off wavelength

Where the sampling length is specified on the drawing, the cut-off length wavelength λc is chosen equal to the sampling length. Where this is not specified then the procedures detailed in **10.3.3** should be used.

10.3.3 Procedure for a non-periodic roughness profile

Surfaces with no repetitive structure, including cast components, sintered and porous materials and sandblasted items, can cause problems in obtaining meaningful roughness measurements. These surfaces are characterized by having a more granular structure than other materials commonly used in engineering. Some of these surfaces exhibit re-entrant features that cannot be traced by the stylus and, therefore, surface texture measurements should be approached with caution.

The following procedure should be applied.

a) Estimate the unknown roughness profile parameter, for example, *Ra* or *Rz*, by visual inspection, use of roughness comparisons of graphical analysis of a profile trace or an unfiltered primary profile measurement.

b) Table 4 and Table 5 show values of sampling length typically associated with different bands of *Ra* and *Rz* values. Select the sampling length corresponding to the parameter estimate in a).

c) Using a measuring instrument, obtain a representative measurement of the chosen parameter using the sampling length estimated in b).

d) Compare the measured parameter value from c) with the range of values given in Table 4 and Table 5 for the sampling length used in c).

e) Where the parameter value lies outside the range of values for the sampling length used, adjust the measuring instrument to the higher or lower sampling length indicated by the value measured in c).

f) If no adjustment was made at e), then the measurement obtained in c) can be regarded as the output from f). If an adjustment was made at e), make a new parameter measurement at the adjusted setting. This value should be in the range for the sampling length used as given in Table 4 or Table 5. If it does not, return to f).

g) Make a representative measurement of the roughness parameter by using the next smaller sampling length than used in f). Depending on the action taken at e), the measurement from c) might already provide some information.

h) Check to see whether the combination of roughness parameter and sampling length from g) corresponds to that which is given in Table 4 or Table 5.

i) Where only the final setting from f) provides a parameter value and sampling length consistent with Table 4 or Table 5 (while g) provided an inconsistent combination) then both the sampling length selection and parameter value indication from f) are correct.

j) Where the measurement at g) also provides a consistent combination of parameter value and sampling length, as given in Table 4 or Table 5, then this shorter sampling length and corresponding parameter value are correct.

k) The correct sampling length is now established by i) and j). Further representative measurements of selected parameters should be made using the cut-off wavelength (sampling length) estimated by them.

Table 4 **Estimates for choosing roughness sampling lengths for the measurement of non-periodic profiles (*Ra*)**

Ra *Ra*/µm	**Roughness sampling length** *lr*/mm	**Roughness evaluation length** *ln*/mm
$0.006 < Ra \le 0.02$	0.08	0.40
$0.02 < Ra \le 0.1$	0.25	1.25
$0.1 < Ra \le 2$	0.80	4.00
$2 < Ra \le 10$	2.50	12.50
$10 < Ra \le 80$	8.00	40.00

Table 5 **Estimates for choosing roughness sampling lengths for the measurement of non-periodic profiles (*Rz*)**

Rz *Rz*1max/µm	**Roughness sampling length** *lr*/mm	**Roughness evaluation length** *ln*/mm
0.025 < *Rz* *Rz*1max ≤ 0.1	0.08	0.40
0.1 < *Rz* *Rz*1max ≤ 0.5	0.25	1.25
0.5 < *Rz* *Rz*1max ≤ 10	0.80	4.00
10 < *Rz* *Rz*1max ≤ 50	2.50	12.50
50 < *Rz* *Rz*1max ≤ 200	8.00	40.00

NOTE 1 Rz is used when measuring Rz, Rv, Rp, Rc and Rt.

NOTE 2 Rz1max is used only when measuring Rz1max, Rv1max, Pr1max and Rc1max.

10.3.4 Procedure for periodic roughness profile

A periodic surface is one that has a structure that repeats at a given spatial frequency, one example being a turned surface. Even ground surfaces show some repetitiveness. On some surfaces these repetitive features are clearly visible, either on the work piece itself or on the profile. The presence of certain repetitive features, however small, can indicate tool wear, machine vibration or machine deficiencies. It is, therefore, important to identify them. Where a profile is perfectly periodic such as in a sine wave, the relationship of a given group of points repeats exactly at a distance equal to the wavelength.

The following procedure should be applied.

a) Estimate graphically the parameter *RSm* of the surface of unknown roughness.

b) Determine the corresponding sampling length using Table 6.

c) Measure the *RSm* value using the sampling length setting determined in b).

d) Where the *RSm* value obtained in c) relates to a smaller or greater cut-off wavelength value than in b), use the smaller or greater cut-off wavelength value. Otherwise, retain the cut-off wavelength (sampling length) used in b).

e) Obtain a representative measurement of the selected parameter(s) using the cut-off wavelength (sampling length) estimated in d).

Table 6 **Estimates for choosing roughness sampling lengths for the measurement of periodic tables**

RSm	**Roughness sampling length**	**Roughness evaluation length**
RSm/mm	*lr*/mm	*ln*/mm
$0.013 < RSm \leq 0.04$	0.08	0.40
$0.04 < RSm \leq 0.13$	0.25	1.25
$0.013 < RSm \leq 0.4$	0.80	4.00
$0.4 < RSm \leq 1.3$	2.50	12.50
$1.3 < RSm \leq 4$	8.00	40.00

11 Calibration

11.1 General

Surface texture measuring instruments are calibrated using material measures. The calibration of a wide range of measuring instruments operating in a variety of conditions demands more than one type of material measure. BS EN ISO 5436-1 distinguishes between five main types of material measure, each of which can have a number of variants. Calibration of a measuring instrument should always use a material measure that matches the surface to be measured.

Whilst the Type A measures given in Table 7 are useful for checking the vertical magnification factor of a measuring instrument, no information is given regarding the calibration of the measuring instrument in the scanning axis. For this, a Type C measure should be used.

Table 7 **Types, names and uses of material measures**

Type	**Name**	**Uses**
A	Depth measurement measures	Calibration of the vertical profile – artefact has wide grooves of a known depth
B	Tip condition measurement measures	Calibration of the condition of the stylus tip – artefact has narrow grooves of various depths and widths
C	Spacing measurement measures	Calibration of the vertical profile may also be used for calibrating horizontal profiles in certain conditions
D	Roughness measurement measures	Overall calibration of the measuring instruments
E	Profile co-ordinate measurement measures	Calibration of the profile co-ordinate system of the measuring instrument

The overall calibration of a measuring instrument, i.e. its overall ability to measure and calculate a surface texture parameter should always be checked. For this, a Type D measure is used.

Lastly, the stylus should always be checked to be performing to its manufacturer's specification. For this, a Type B measure is used.

Users of surface texture measuring instruments should have at least four material measures available to them that have been previously calibrated using a higher-accuracy, traceable system. Type E measures are also required for checking the form measuring capabilities of a measuring instrument. The material measure types detailed above should be calibrated in accordance with BS EN ISO 5436-1. Interferometers or another stylus instrument that has been traceably calibrated may be used. There should be an unbroken and documented chain of calibration to the definition of the metre in accordance with BS EN ISO 9000.

Each of the calibration artefacts has a limited range of application according to its own characteristics and those of the measuring instrument to be calibrated. Table 7 summarizes the types of artefact specified in BS EN ISO 5436-1.

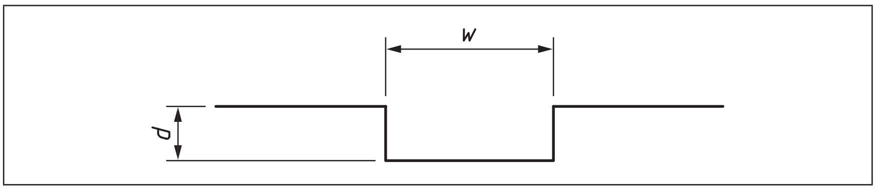
Subtypes of each material measure type are given in **11.2** to **11.6**.

11.2 Type A: Depth measurement measures

11.2.1 Type A1

Type A1 measures have wide calibrated grooves with a flat bottom, a ridge with a flat top, or a number of such separated features of equal or increasing depth or height (see Figure 20). Each feature is wide enough to accommodate the shape or condition of the stylus tip. A minimum of five traces should be taken. The traces should be taken from evenly spaced areas across the measuring window.

Figure 20 **Type A1 material measure**



Type A1 measures should be measured in accordance with the following.

a) Draw a continuous straight mean line equal in length to three times the width of the groove over the groove to represent the upper level of the surface and another to represent the lower level, both lines extending symmetrically about the centre of the groove.

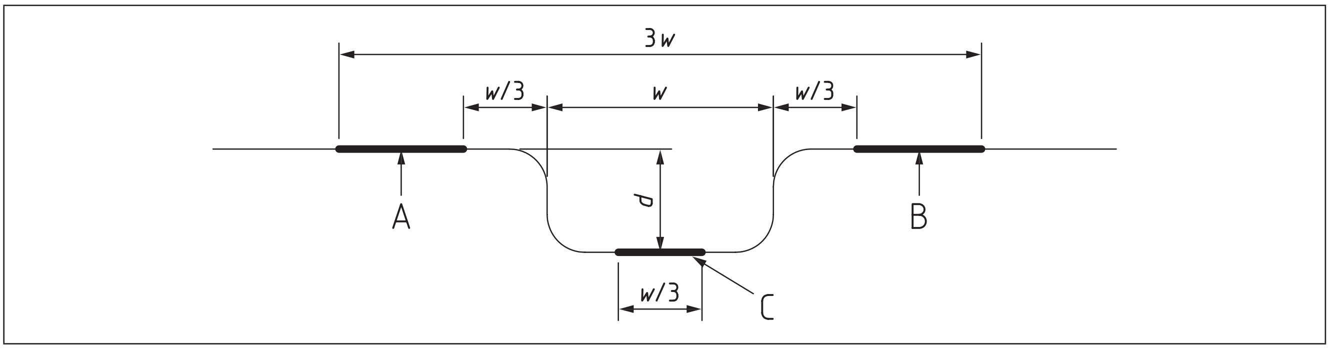
b) Do not include the upper surface on each side of the groove for a length equal to one-third of the width of the groove in the calibration process. This is to avoid anomalies from rounded corners.

c) Measure the surface at the bottom of the groove over the central third of its width, A, B and C (see Figure 21).

d) Measure the depth, *d*, perpendicularly to the traverse axis from the upper mean line to the mid-point of the lower mean line.

e) Take a minimum of five traces from evenly spaced areas across the measuring window.

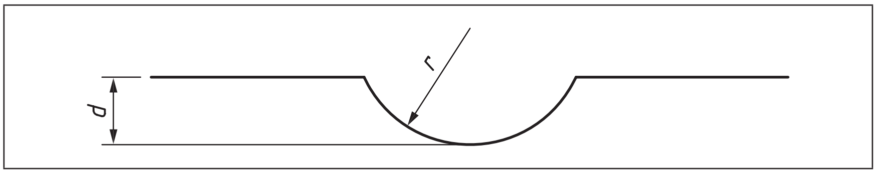
Figure 21 **Procedure for the assessment of Type A1 measures**



11.2.2 Type A2

This material measure is similar to Type A1 except that the grooves have rounded bottoms (see Figure 22). The radius is sufficiently large not to be affected by the shape or condition of the stylus tip. A minimum of five traces should be taken. The traces should be taken from evenly spaced areas across the measuring window.

Figure 22 **Type A2 material measure**



11.3 Type B: Tip condition measurement measure

11.3.1 Type B1

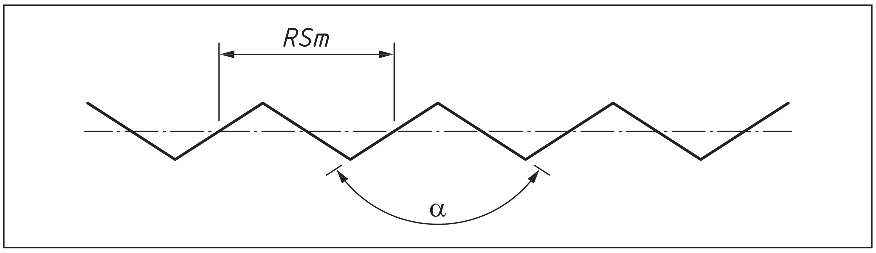
Type B1 measures have narrow grooves or a number of separated grooves of different width designed to be increasingly sensitive to the dimensions of the stylus tip. The grooves have rounded bottoms with radiuses that are sensitive to the stylus tip.

11.3.2 Type B2

These material measures have two or more groove patterns on a common base. Comparing *Ra* on each groove patch indicates the stylus condition. A minimum of eighteen traces should be taken. The traces should be taken from evenly spaced areas across the measuring window. A filter should be used having a λc cut-off either in accordance with the calibration certificate or in accordance with BS EN ISO 4287.

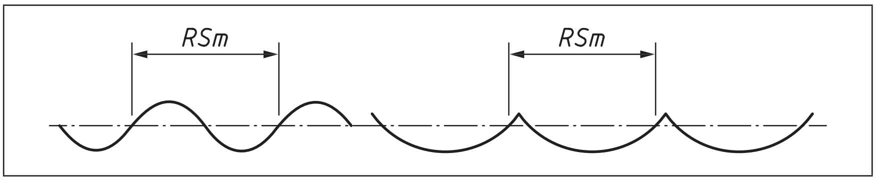
The sensitive groove pattern is formed by isosceles triangular grooves that have sharp peaks and valleys (see Figure 23). The *Ra* is dependent on the size of the stylus tip.

Figure 23 **Type B2 material measure**



The insensitive groove pattern is formed by sinusoidal or arcuate grooves that make *Ra* independent of the stylus tip (see Figure 24).

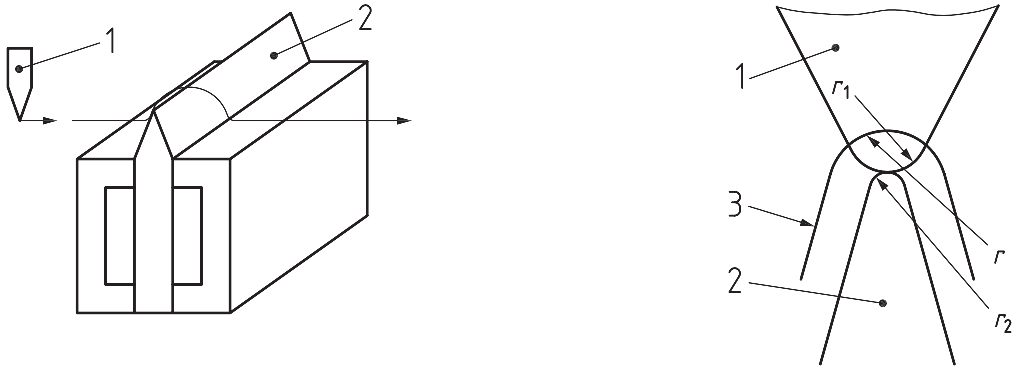
Figure 24 **Type B2 material measure**



11.3.3 Type B3

This material measure has a fine protruding edge. The radius and apex angle should be smaller than the radius and apex angle of the stylus being calibrated. The stylus condition can be assessed by traversing the artefact and recording the surface profile. This method can only be used with direct profiling measuring instruments with low traversing speeds. An example of a Type B3 measure in use that has been produced using a sharp razor blade is shown in Figure 25.

Figure 25 **Type B3 material measure**



a) Schematic diagram of razor blade trace for profiling the shape of a stylus tip to determine its radius

b) The output profile represents the stylus tip shape where the radius and apex angle of the razor blade are much finer

Key

1 Stylus
2 Razor blade
3 Recorded profile

11.4 Type C: Spacing measurement material measure

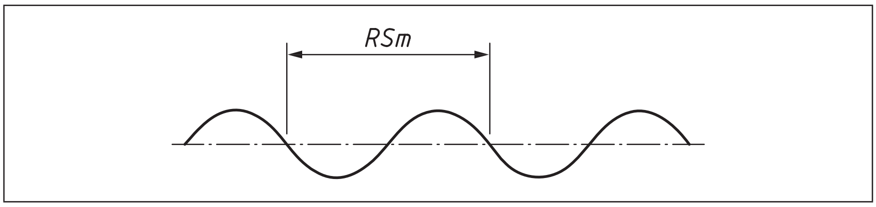
11.4.1 General

These material measures are used mainly for calibrating vertical profile components. However, they can be used for calibrating horizontal profile components, provided that the spacing of the grooves is within limits that are acceptable for this purpose. They have repetitive grooves with various shapes.

11.4.2 Type C1

This material measure has grooves having a sine wave profile and is characterized by *RSm* and *Ra* (see Figure 26). The user should choose values that ensure that the attenuation by the stylus or filter is negligible. A minimum of twelve traces should be taken. The traces should be taken from evenly spaced areas across the measuring window. The parameters should be calculated in accordance with BS EN ISO 4287.

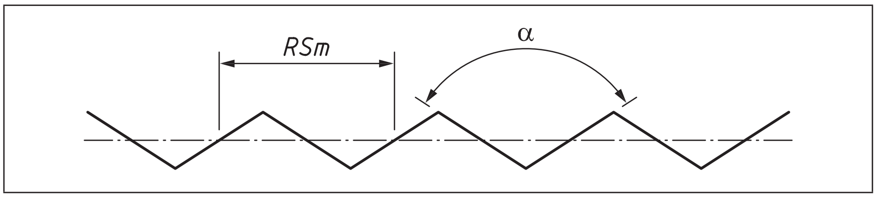
Figure 26 **Type C1 material measure**



11.4.3 Type C2

This material measure has grooves having an isosceles triangular profile and is characterized by *RSm*, *Ra* and the angle α (see Figure 27). The user should choose values that ensure that the attenuation by the stylus or filter is negligible. A minimum of twelve traces should be taken. The traces should be taken from evenly spaced areas across the measuring window. The parameters should be calculated in accordance with BS EN ISO 4287.

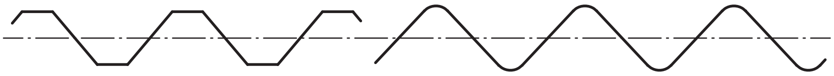
Figure 27 **Type C2 material measure**



11.4.4 Type C3

This material measure simulates approximate sine wave grooves by means of a triangular profile with rounded or truncated peaks and valleys (see Figure 28). A minimum of twelve traces should be taken. The traces should be taken from evenly spaced areas across the measuring window. The parameters should be calculated in accordance with BS EN ISO 4287.

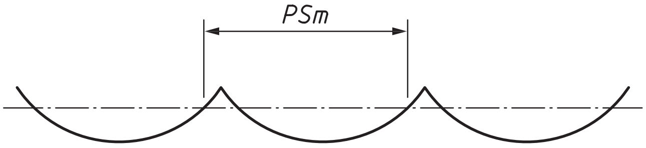
Figure 28 **Type C3 material measure**



11.4.5 Type C4

This material measure has grooves with an arcuate profile and is characterized by *PSm* and *Pa* (see Figure 29). The user should choose values that ensure that the attenuation by the stylus is negligible. A minimum of twelve traces should be taken. The traces should be taken from evenly spaced areas across the measuring window. The parameters should be calculated in accordance with BS EN ISO 4287.

Figure 29 **Type C4 calibration artefact**



11.5 Type D: Roughness measurement material measure

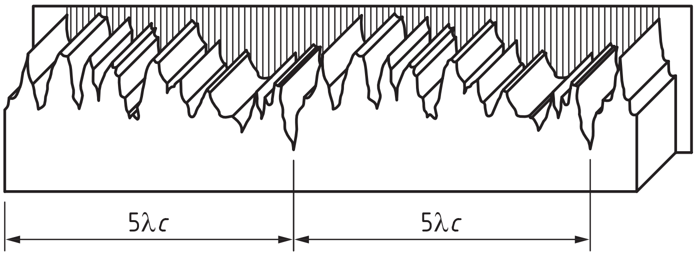
11.5.1 General

These material measures are commonly used for the overall calibration of measuring instruments. A statistically determined number of measurement positions spread across the surface should be averaged for a Type D measure.

11.5.2 Type D1: Unidirectional irregular profile

This material measure has an irregular profile in the direction of the traverse (similar to a ground profile). This irregular profile is repeated in the longitudinal direction after a number (usually five) of the sampling lengths for which it is designed (see Figure 30). The profile shape is isotropic normal to the measuring direction of the material measure. The material measure simulates work pieces containing a range of different sized crest spacings and provides an overall check on calibration. The material measure is characterized by *Ra* and *Rz*.

Figure 30 **Type D1 material measure**

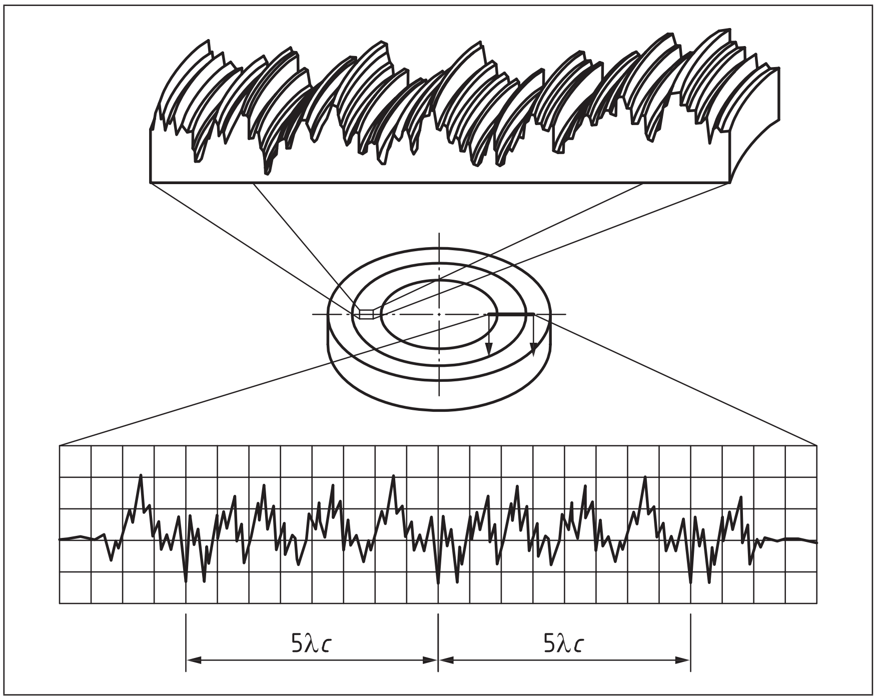


A minimum of twelve traces should be taken from evenly spaced areas across the measuring window. The parameters should be calculated in accordance with BS EN ISO 4287. These artefacts should be used only at the cut-off specified on their calibration certificates.

11.5.3 Type D2: Circular irregular profile

This material measure is characterized by *Ra* and *Rz* and has irregular profiles repeated every $5\lambda c$ in the radial direction (see Figure 31). Normal to the measuring direction of the artefact (in the circumferential direction), the profile shape is isotropic. A minimum of twelve traces should be taken. The traces should be taken from evenly spaced areas across the measuring window. The parameters should be calculated in accordance with BS EN ISO 4287. These artefacts should be used only at the cut-off specified on their calibration certificates.

Figure 31 **Type D2 material measure**



11.6 Type E: Profile co-ordinate measurement material measure

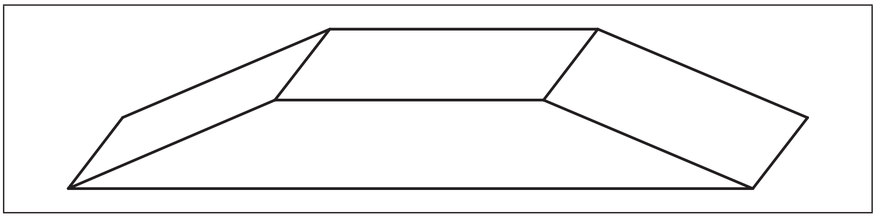
11.6.1 Type E1 – Spherical dome

This material measure is characterized by its radius and *Pt*. The user should ensure that the radius of the sphere or hemisphere allows the stylus tip to remain in contact with the surface. The user should ensure that it does not fall on the stem of the stylus during the traverse. The traverse should be set symmetrically either side of the highest point of the intended trace.

11.6.2 Type E2 – Trapezoidal

This material measure is a precision prism characterized by the angles between the surfaces and *Pt* on each surface (see Figure 32). The size and shape of the material measure should be such that the stylus tip remains in contact with the surface and does not fall on the stem of the stylus during the traverse. The traverse should be chosen to give a symmetrical trace over the profile. The length of the top plane should be checked to be long enough to allow the material measure to be levelled in a stable manner.

Figure 32 **Type E2 material measure**



11.7 Calibration procedure

The measuring instrument should be calibrated at the place of use. Ambient conditions that influence the measuring instrument when in use should be considered. Before calibration, the operation of the stylus instrument should be checked against the manufacturer’s operating instructions.

The calibration procedure should be as follows.

a) Align the artefact to within 10% of the measuring range.

b) Select the following measuring conditions:

   1) sampling length;

   2) evaluation length; and

   3) cut-off wavelength.

c) Carry out the selected measurements on each material measure distributed over the measurement surface.

11.8 Type F: Software

BS EN ISO 5436-2 defines and specifies two types of software measurement standard (Type F1 and Type F2) that are designed to verify the software of a surface texture measuring instrument through its filter algorithms and parameter calculations, for example.

Type F1 software measurement standards are reference data files known as “softgauges”, which are digital representations of a primary profile. To test software, these softgauges are input to the software under test and the results compared to the certified results provided with the Type F1 software measurement standard.

Type F2 software measurement standards are reference software. Reference software consists of computer software with which the software in a measuring instrument can be compared. To test measuring instrument software, a common data set is input to both the Type F2 software measurement standards and the software under test and then the results from the software under test compared to the certified results from the reference software.

12 Uncertainties

12.1 General

*Commentary on **12.1***
For a basic understanding of measurement uncertainties, see the NPL Measurement Good Practice Guide 11 (Issue 2), A beginner's guide to uncertainty of measurement *by Stephanie Bell [1]. For a more thorough understanding of the subject, see the UKAS publication M3003,* The expression of uncertainty and confidence in measurement *[2] and PD 6461-3,* Vocabulary of metrology – Part 3: Guide to the expression of uncertainty in measurement *(popularly known as the ISO GUM).*

The number of factors involved in the measurement of surface texture and the complexity of the process mean that it is not easy to calculate measurement uncertainties. The following method is for a simplified uncertainty analysis. The results obtained from this method tend to overestimate the uncertainty measurement of a stylus instrument. The final uncertainty figures become the uncertainty figures in the measurement of displacement in the x and z axes of the measuring instrument. These values should always be stated on a calibration certificate or with a measurement report.

Calculating the uncertainties in some surface texture parameters, for example *Ra*, can be complicated and is often only carried out by laboratories specializing in traceability. However, the uncertainty in certain surface texture parameters, such as *Rp* or *Rv* can be calculated using the method described in **12.2**.

It is important to be aware that this uncertainty analysis relies on at least twelve repeat measurements being made on a surface (with the exception of the five measurements of the Type A1 or Type A2 artefact.

12.2 Uncertainty in the measurement of a vertical displacement

A Type A1 or Type A2 artefact should be used to calibrate the accuracy of the pick-up and transducer arrangement or the vertical magnification factor of the measuring instrument. The artefact is usually supplied with a traceable calibration certificate on which there are at least two numbers of interest (d_C and U_{d_C}).

Once the artefact has been measured and the measuring instrument corrected to give the closest reading it can to the value of the step height stated on the certificate, the corrected measurement of a vertical height, Z, is given by:

$$Z = CZ_m \tag{8}$$

where:

Z_m is the measured height;

C is the calibration factor obtained from the following equation:

$$C = \frac{d_C}{d_m} \tag{9}$$

where:

d_m is the step height measured by the measuring instrument; and

d_C is the step height stated on the calibration certificate.

BS EN ISO 5436-1 advocates that a minimum of five measurements should be taken to determine d_m. Z_m is a function of a number of factors, but the most influential are represented in the following equation.

$$Z_m = Z_p + Z_{ref} + Z_n + Z_{pl} + Z_{tip} \tag{10}$$

where:

Z_m is the measured height;

Z_p is the traced profile;

Z_{ref} is the slideway profile;

Z_n is the measuring instrument noise;

Z_{pl} is the plastic deformation error; and

Z_{tip} is the effect of tip geometry.

When measuring influence quantities (see **12.3**), the measuring instrument should already have been calibrated and corrected in accordance with **11.7** to **12.2** (i.e. the value of C is close to unity).

12.3 The influence quantities

12.3.1 The traced profile, Z_p

Z_p is the actual height value at a given point in the measurement. Z_p does not affect this uncertainty analysis.

12.3.2 Slideway profile, Z_{ref}

A measurement of height is affected by any imperfections in the profile of the datum slideway or skid. To determine the effect of the datum, either an optical flat or the top surface of a Type E2 artefact should be measured over the traverse length of interest. From this profile it is necessary to determine the largest deviation from a best-fit mean line, i.e. the *Pt* value for the profile ($Z_{ref} = Pt$). This value tends to make the measurement uncertainty larger than it is for a specific area of the datum, but never allows the measurement uncertainty to be too small.

12.3.3 Measuring instrument noise, Z_n

Every measuring instrument has a noise level that can be determined by taking a measurement without moving the slideway. Alternatively, a high quality optical flat or the top surface of a Type E2 artefact should be measured over the traverse length that will be used in practice and the *Pq* value determined ($Z_n = Pq$).

Where an optical flat or Type E2 artefact is used, it should be flatter than and have a smoother surface texture than the resolution of the measuring instrument.

12.3.4 Plastic deformation error, Z_{pl}

Plastic deformation of the surface can occur. This is dependent on the stylus and surface materials, the stylus force and shape and the local curvature or slopes on the surface. The contribution of this term to the uncertainty analysis is difficult to calculate, but a value of Z_{pl} equating to 20 nm is suggested unless further calculations can be carried out to determine a more accurate value of Z_{pl}.

12.3.5 Effect of tip geometry, Z_{tip}

This uncertainty contribution is only required when measuring surfaces with wavelength structures that are less than the radius of the stylus tip. It is extremely difficult to calculate the effect of the tip geometry on a vertical height measurement. Therefore, the tip condition should always be checked using a Type B gauge and any measurements made should be documented in writing with the following disclaimer, “The surface has been measured with a stylus of tip radius r µm, and wavelength structures less than r µm are distorted”.

12.4 Other factors of influence

There are a number of further factors that affect a surface texture measurement. For example, the measuring instrument can expand due to temperature variations in the room, the measuring instrument could vibrate or filters could have a detrimental effect on the readings. The effect of the filters is to distort some wavelength structures around the cut-off of the filters. For the purposes of this uncertainty analysis, a disclaimer should be added to any measurements that state the cut-off wavelengths used. For example, “The surface has been measured using a cut-off wavelength, λc, of 0.8 mm”. Where other filters are used, such as λs and λf filters, the cut-off values should be stated.

12.5 Calculation of the total uncertainty in a vertical displacement

The total uncertainty, U, in measuring a height, Z, is calculated by inserting the influence factors given in **12.3** and **12.4** into equation (11).

$$U_{\mathrm{Z}}^2 = Z_{\mathrm{m}}^2 U_{\mathrm{C}}^2 + C^2 U_{Z_{\mathrm{m}}}^2 \tag{11}$$

where:

U_{C} is the uncertainty in the calibration constant; and

$U_{Z_{\mathrm{m}}}$ is the uncertainty in the actual measurement of a height, Z_{m}.

U_{C} is obtained from the equation:

$$U_{\mathrm{C}}^2 = \frac{U_{d_{\mathrm{C}}}^2}{d_{\mathrm{m}}^2} + \frac{d_{\mathrm{C}}^2 U_{d_{\mathrm{m}}}^2}{(d_{\mathrm{m}}^2)^2} \tag{12}$$

where:

$U_{\mathrm{d_m}}$ is the standard deviation of the repeated results to determine d_{m};

$U_{\mathrm{d_c}}$ is the uncertainty stated on the calibration certificate of the calibration artefact (this value might require a conversion factor);

d_{m} is the measured value of the depth of the Type A1 artefact; and

d_{C} is the calibrated value of the depth of the Type A1 artefact given on the certificate.

U_Z is obtained from the following equation:

$$U_Z{}^2 = \frac{Z_{ref}{}^2}{12} + Z_n{}^2 + \frac{Z_{pl}{}^2}{3} \tag{13}$$

where:

Z_{ref} is the error in the slideway profile (in this case an optical flat was measured as having a *Pt* value of 27 nm);

Z_n is the measuring instrument noise (in this case an optical flat was measured as having a *Pq* value of 14 nm);

Z_{pl} is the error due to plastic deformation (in this case taken as 20 nm).

Once the values for the above terms have been calculated, the value for U_Z can be found by calculating a square root. This is known as the combined standard uncertainty. To calculate an uncertainty at 95% confidence, U_{TZ} or U_Z should be multiplied by two.

12.6 Uncertainty in the displacement in the traverse direction

The complexity of calculating the uncertainty in a displacement measurement in the direction of the scan or x axis means that only laboratories specializing in traceability carry out these calculations. An uncertainty in the x axis should only be stated when giving a spacing or hybrid surface texture parameter. A Type C artefact should be used to calibrate a displacement in the x axis with an *RSm* measurement that is as close as practicable to that of the surface being measured. At least twelve measurements should be made over different sections of the x axis. To first approximation the uncertainty in the measurement of a spacing parameter is the standard error of the mean of the results of the repeat measurements. The expanded uncertainty (at 95% confidence) is then twice the standard error of the mean.

Calculation of the uncertainty for a hybrid parameter is outside the scope of this British Standard. Where a hybrid parameter is stated or appears on the certification, the following disclaimer should be placed on it, “The uncertainty in this parameter has not been calculated, but the uncertainty in the x axis is U_x µm and the uncertainty in the z axis is U_z µm”.

12.7 Uncertainties in the surface texture parameters

12.7.1 Uncertainty in the amplitude parameters

The uncertainty in *Rp*, *Rv*, *Rz*, *Rc* and *Rt* is found by simply substituting the parameter value for *Z* in equation (11) and combining this in quadrature with the standard deviation of repeated measurements at least twelve measurements over different areas of the surface.

12.7.2 Uncertainty in the amplitude parameter (average of ordinates)

The uncertainty in *Ra*, *Rq*, *Rsk* and *Rku* cannot be calculated due to the complexity of the definition of these parameters. When quoting or certifying these parameters, twice the standard error of the mean of at least twelve measurements over different areas of the surface should be stated along with the disclaimer, “The uncertainty in this parameter has been taken as twice the standard error of the mean of the measurements across the surface. The uncertainty in the z axis is U_z µm”.

12.8 Worked example of an uncertainty calculation for ACMESURF

The following is an example of an uncertainty calculation for an imaginary measuring instrument known hereafter as ACMESURF. ACMESURF has been calibrated in the z axis using a Type A1 artefact and has calibrated in the x axis using a Type C1 artefact.

The uncertainty in the z displacement should be considered first. To determine *U* from equation (11), equations (12) and (13) should be calculated.

Equation (12) should be used with values where:

d_m is the measured value of the depth of the Type A1 artefact using ACMESURF (in this case 330 nm);

d_C is the calibrated value of the depth of the Type A1 artefact stated on the certificate (in this case 301 nm);

U_{d_m} is the standard deviation of five repeat measurements of d_m using ACMESURF (in this case 30 nm);

U_{d_C} is the uncertainty in the calibrated depth of the Type A1 artefact stated on the calibration certificate (in this case ±12 nm, but this is stated with a coverage factor of 2 so the value of U_{d_C} is actually ±6 nm).

Equation (12) therefore becomes:

$$U_C{}^2 = \frac{6^2}{330^2} + \frac{301^2 \times 30^2}{(330^2)^2} = 0.007\,2 \tag{14}$$

Therefore:

$$U_C = \sqrt{0.007\,2} = 0.084\,9 \text{ nm}$$

Inserting these values into equation (13) gives the following equation:

$$U_Z{}^2 = \frac{27^2}{12} + 14^2 + \frac{20^2}{3} = 390.08 \tag{15}$$

Therefore:

$$U_Z = \sqrt{390.08} = 19.751 \text{ nm} \tag{16}$$

Equation (11) should now be calculated, as follows:

$$U_Z{}^2 = Z^2 \times 0.008\,49^2 + 0.912\,4^2 \times 19.751^2 = 324.750 + 0.007\,2 \times Z^2 \tag{17}$$

where:

U_C is 0.008 49 nm, as calculated from equation (12);

C is 301/330 = 0.912 4, calculated from the ratio of *dC* to *dm;*

U_{Z_m} is 19.751 nm, calculated from equation (13); and

Z_m is the *z* displacement that is measured.

Finally, the expanded uncertainty at 95% confidence is given by the equation:

$$U_{TZ} = 2 \times \sqrt{324.750 + 0.007\,2 \times Z^2} \text{ nm} \tag{18}$$

Table 8 gives the change in U_{TZ} with measured height, Z. The term in the equation for U_{TZ} that depends on Z only begins to take effect around 100 nm.

Table 8 **Change of the total uncertainty in a height measurement**

Z nm	U_{TZ} nm
1	37
10	37
100	40
1 000	174

To calculate the uncertainty in the x direction, a Type C3 sinusoidal artefact with a period of 0.25 µm is measured by ACMESURF in twenty locations and the *RSm* value calculated for each measured profile. A mean value of 0.256 µm with a standard deviation of 18 nm is calculated from the *RSm* values. As stated in **12.6**, the value of the standard error of the mean is the value given as the standard uncertainty, so the combined uncertainty in a measurement of displacement in the x axis is U_{TX} ±8 nm at 95% confidence (2 × 18/√20).

Twelve measurements are then made using ACMESURF of *Rp*, *Ra* and *RSm*. The mean value of *Rp* is calculated to be 1 213 nm with a standard deviation of 57 nm, the mean value of *Ra* is 45 nm with a standard deviation of 7 nm and the mean value of *RSm* is 108 nm with a standard deviation of 31 nm. The measurement results should be given as in Table 9.

To calculate the standard error of the mean, the standard deviation is divided by the square root of the number of measurements, in this case twelve. The uncertainty in *Rp* is calculated by adding 57 nm in quadrature with 209 nm, i.e:

$$\sqrt{57^2 + 209^2} = 217\,\text{nm} \tag{19}$$

Table 9 **Stated uncertainties for measurements made with ACMESURF**

Parameter	Parameter value nm	Standard deviation nm	Uncertainty nm
Rp	1 213	57	217
Ra	45	7	4
RSm	108	31	8

The table and the following disclaimers should be documented in writing:

a) "The uncertainty in *Ra* has been taken as twice the standard error of the mean of 12 repeated measurements across the surface. The uncertainty in the z axis is $2 \times \sqrt{391.285 + 0.010 \times Z^2}$ nm"; and

b) "The uncertainty in *RSm* has not been calculated, but the uncertainty in the x axis is 10 nm".

Annex A (informative) Parameter overview

A.1 Recent and out-of-date parameters

Table A.1 gives recent and out-of-date parameters.

NOTE Table A.1 also states whether the parameter is calculated over a sampling length or the evaluation length.

Table A.1 **Old and new surface texture parameters, ISO 4287:1997**

Parameters, 1997	**1984**	**1997**	**Determined within**	
			Evaluation length	**Sampling length**
Maximum profile height	*Rp*	*Rp*		X
Maximum profile valley depth	*Rm*	*Rv*		X
Maximum height of profile	*Ry*	*Rz*		X
Mean height of profile	*Rc*	*Rc*		X
Total height of profile	—	*Rt*	X	
Arithmetical mean deviation of the assessed profile	*Ra*	*Ra*		X
Root mean square deviation of the assessed profile	*Rq*	*Rq*		X
Skewness of the assessed profile	*Sk*	*Rsk*		X
Kurtosis of the assessed profile	—	*Rku*		X
Mean width of profile elements	*Sm*	*RSm*		X
Root mean square slope of the assessed profile	Δq	$R\Delta q$		X
Material ratio of the profile		*Rmr(c)*	X	
Profile section height difference	—	$R\delta c$	X	
Relative material ratio	*Tp*	*Rmr*	X	
Ten point height (deleted as an ISO parameter)	*Rz*	—		

A.2 Parameters previously in general use

A.2.1 General

The following descriptions might appear on older machines and in older literature.

A.2.2 Roughness profile: *R*

The roughness profile is an assessed profile, which is obtained from the primary profile by filtering out the waviness component as specified by the cut-off length λc. It is important to be aware that the λc described in Annex A and used by some older measuring instruments differs in its meaning from its current usage.

A.2.3 Filtered waviness profile: *WC*

The filtered waviness profile is an assessed profile that is obtained from the primary profile by filtering out the roughness component as specified by cut-off length λf. It is important to be aware that the λf in Annex A that is used by some older measuring instruments differs in its meaning from its current usage.

A.2.4 Filtered centre line waviness profile: WCA

The filtered centre line waviness profile is an assessed profile that is obtained from the primary profile by filtering the waviness components, as specified by λc, and the roughness components, as specified by λf, while passing mid-range waves.

A.3 Sampling length: *L*

The sampling length is the minimum evaluation length used to obtain an evaluation value from an assessed profile, according to the selected parameter. The sampling lengths of roughness and waviness profiles are identical to cut-off length λc and λf, respectively. The sampling length of WCA corresponds to λf.

A.3.1 Evaluation length: *ln*

The evaluation length is the sum of a number of (integer) sampling lengths. This is the entire length of a profile over which data is collected. A standard roughness evaluation length comprises five sample lengths. The sample length is always equal to the filter cut-off length. In typical evaluation of the surface texture, all of the data logged in each sampling length is averaged throughout the evaluation length, yielding the evaluation value (such as *Ra*, *Rq*, *Ry*, *Pc*, *Sm*, HSC and *S*). However, depending on the parameters, the evaluation values can use the maximum value of the entire length (e.g. *Ry*, *Rp*, *Rv*, *Rt*).

A.3.2 Traverse length: *lt*

The traverse length equals the sum of the evaluation length, pre-travel length and post-travel length. The evaluation length is shorter than the traverse length to eliminate the effects of drive motors accelerating and decelerating and also electrical filters settling down.

A.3.3 Average ten point height of irregularities: *Rz*

The ten point height of irregularities is the difference between the average height of the five highest peaks from the mean line and the average depth of the five deepest valleys from the mean line. This parameter is used to reduce the effect of the odd scratches or spurious irregularities. It requires only one sampling length and is, therefore, useful when only a short length of surface is available for measurement.

A.3.4 Third point height: R_{3Z}

This parameter provides a simpler method of obtaining the kind of average value that *Rz* provides but uses two instead of ten points. It is the distance between the third highest peak and the third lowest valley. The two parameters give the same result. The method is to be regarded as a means of estimating the actual mean given by *Rz*.

A.3.5 Maximum height of the profile: *Ry*

The maximum height of the profile is the distance between the maximum peak height and the minimum valley depth from the mean line in each sampling length. *Ry* is the mean value of the maximum peak-to-valley heights in the evaluation length.

A.3.6 Total peak-to-valley height: *Rt*

The total peak-to-valley height is the sum of the maximum profile peak height *Rp*max and the maximum profile valley depth *Rv*max, the vertical height between the highest and lowest points on the profile within the evaluation length. *Rt* is used to specify maximum roughness height rather than the mean height that *Ra* gives. This parameter is used when tactile assessment of the surface is required for handling purposes.

A.3.7 Peak-to-valley heights

The peak-to-valley values are as follows.

- The maximum peak-to-valley height within the sampling length *L* is *R*max.
- The mean value of the *R*max of five consecutive sampling lengths is *Rtm*.
- The height of the highest point of the profile above the centre line within the sampling length *L* is *Rp*.
- The mean value of the Rp of five consecutive sampling lengths is Rpm.

A.3.8 Peak count: *Pc*

The peak count is the number of peak-valley pairs, referred to as cycles, per unit length along the mean line of the profile within the sampling length. Two lines, referred to as count levels, are drawn at equal distances above and below the mean line, running parallel to it. Each profile cycle between intersections of the profile and the mean line, between which a peak projects above the upper count level and an adjacent valley drops below the lower count level, is counted as one peak-valley cycle.

A.3.9 Mean spacing of profile irregularities: *Sm*

The mean spacing of profile irregularities is equal to the mean wavelength of the peak-valley cycles. It is the reciprocal of the *Pc* value.

A.3.10 High spot count: HSC

High spot count is the number of peaks per unit length along the mean line of the profile within the sampling length. A line, referred to as a count level, is drawn above the mean line, running parallel to it. Each peak that projects above the specified count level and has a local peak is known as a high spot count peak. A local peak should have valleys on both sides, which are *Ry*/100 or more below the peak, or should be *L*/100 or more to the left and right from both adjacent peaks.

A.3.11 Mean spacing of local peaks of the profile: *S*

The mean spacing of the local peaks of the profile is equal to the mean of peak-to-peak distances of the local peaks.

A.3.12 Amplitude distribution curve: ADC

The assessed profile is divided by lines parallel to the mean line at equal intervals and the ratio of each area (which is determined by summing the sampling dots) between two adjacent lines to the area over the evaluation length is defined as the amplitude distribution. The amplitude distribution curve is created by plotting the level of each of the parallel lines on the y axis and the obtained amplitude distribution (%) on the x axis.

A.3.13 Material ratio of the profile: mr

The material ratio of the profile is the ratio of the bearing length to the evaluation length. It is represented as a percentage. The bearing length is the sum of section lengths obtained by cutting the profile with a line (slice level) drawn parallel to the mean line at a given level. The ratio is assumed to be 0% if the slice level is at the highest peak and 100% if it is at the deepest valley. Parameter mr determines the percentage of each bearing length ratio of a single slice level or nineteen slice levels. These are drawn at equal intervals within *Rt*. Parameter δc (plateau ratio) determines the distance between the two slice levels that are represented by two different percentages. The parameter mr*d* determines the percentage of a slice level each time it is moved down at equal intervals from a given level in the profile.

A.3.14 Bearing area curve: BAC

The bearing area curve is the graph obtained by plotting bearing length ratios (mr) on the x axis against their corresponding slice level depths or heights on the y axis. BAC1 graph shows the depths of the slice level (100% down to 0% of *Rt*) on the y axis; BAC2 is the graph that displays the heights on the y axis. It is important to be aware that the y axis in previous standards is referred to as the z axis in current standards.

A.3.15 Bearing ratio: *tp*

This is the ratio, expressed as a percentage, of the length of bearing surface at any specified depth in the profile to the evaluation length. When components move into contact with one another wear takes place and the bearing ratio simulates the effect of this wear. There are limitations to the accuracy of the bearing ratio for predicting wear as the measurement is taken over a length and not an area. It is determined over a short sample length and does not take waviness and form into account.

A.3.16 Core roughness depth: *Rk*

Where a straight line passes through two points that pinpoint the 40% difference in mr and the minimal difference in height on the BAC2 graph, the core roughness depth, *Rk*, is the difference between the heights of the slice level at 0% of mr and at 100% of mr on the straight line.

The following parameters are obtained from the BAC graph:

a) reduced peak height: *Rpk*;

b) reduced valley height: *Rvk*;

c) reduced peak area: A1;

d) reduced valley area: A2;

e) material ratio 1: mr1; and

f) material ratio 2: mr2.

A.3.17 Average wavelength: λa or λq

The average wavelength of the profile includes the spacings of every point on the flanks as well as the crest spacing. It is derived mathematically from the Fourier analysis. Numerically, average wavelength is expressed as a length.

Bibliography

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

PD 6461-3, *Vocabulary of metrology – Part 3: Guide to the expression of uncertainty in measurement*

Other publications

[1] BELL, S. *Measurement good practice guide 11: A beginner's guide to uncertainties of measurement*. Issue 2. London: The Stationery Office, 2001. ISSN 1368 6550. 2)

[2] UNITED KINGDOM ACCREDITATION SERVICE. *The expression of uncertainty and confidence in measurement.* Edition 2. Feltham: UKAS, 2007. 3)

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2) A copy of this publication can be requested from the British Library Document Supply Centre, Boston Spa, Wetherby, West Yorkshire, LS23 7BQ or downloaded from http://publications.npl.co.uk.

3) A copy of this publication can be requested from the United Kingdom Accreditation Service, 21–47 High Street, Feltham, Middlesex TW13 4UN or downloaded from www.ukas.com.

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