

Good Practice Guide No. 37

The Measurement of Surface Texture using Stylus Instruments

Richard K Leach



Measurement Good Practice Guide No. 37

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ABSTRACT

This guide covers the measurement of surface texture using a stylus instrument. It describes the current international standards, introduces the terminology associated with surface texture measurement, and describes how to make measurements and how to interpret the results. The guide also covers the calibration of surface texture measuring instruments and informs the user of such instruments how to calculate measurement uncertainties.

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Extracts from ISO 3274: 1996, ISO 4287: 1997, ISO 13565-1: 1996 and ISO 5436-1: 2000 are reproduced with permission of BSI under licence number 2001SK/0166. Complete editions of the standard can be obtained from BSI Customer Services, 389 Chiswick High Road, London W4 4AL (Tel + 44(0)20 8996 9001).

Draft International Standards are subject to change. Reference should be made to the final published version of the standard when applicable.

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The Measurement of Surface Texture using Stylus Instruments

Preface

The author hopes that after reading this Good Practice Guide you will be able to understand the correct way to make measurements with surface texture instruments. The content is written at a simpler technical level than many of the standard textbooks so that a wider audience can understand it. I am not trying to replace a whole raft of good textbooks, operator's manuals, specifications and standards, rather present an overview of good practice and techniques.

“Metrology is not just a process of measurement that is applied to an end product. It should also be one of the considerations taken into account at the design stage. According to the Geometrical Product Specification (GPS) model, tolerancing and uncertainty issues should be taken into account during all stages of design, manufacture and testing. The most compelling reason is that it is often considerably more expensive to re-engineer a product at a later stage when it is found that it is difficult to measure, compared to designing at the start with the needs of metrology in mind.” Professor Richard Leach 2003.

GOOD MEASUREMENT PRACTICE

There are six guiding principles to good measurement practice that have been defined by NPL. They are:

The Right Measurements: *Measurements should only be made to satisfy agreed and well-specified requirements.*

The Right Tools: *Measurements should be made using equipment and methods that have been demonstrated to be fit for purpose.*

The Right People: *Measurement staff should be competent, properly qualified and well informed.*

Regular Review: *There should be both internal and independent assessment of the technical performance of all measurement facilities and procedures.*

Demonstratable Consistency: *Measurements made in one location should be consistent with those made elsewhere.*

The Right Procedures: *Well-defined procedures consistent with national or international standards should be in place for all measurements.*

Introduction

1

IN THIS CHAPTER

- What this guide is about and what it is not
- Introduction to surface texture

This measurement good practice guide provides an overview of the use of stylus-based surface texture instruments. It is an update to a guide first published in 2001 and has been updated to reflect changes in the specification standards over the last ten years.

What this guide is about and what it is not

It is intended that this guide should give enough information so that the metrologist can make best use of stylus instruments when measuring surface texture. The guide also covers good practice regarding the calculation of surface texture parameters. This good practice guide is not intended to be an authoritative guide to the surface texture specification standards and the primary reference should always be the standards themselves.

Introduction to surface texture

Often the surface of a workpiece appears to the human eye to be flat and smooth. The surface may feel smooth if one runs a finger across it, but examining this surface under a magnifying device will reveal a complex structure that is a result of such factors as crystal structure and paint on the surface plus the processes that have been used to manufacture it. Such structure is termed “texture” and 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, one first has to measure it. Measuring during the manufacturing cycle can influence decisions taken on machining systems and processes allowing surfaces to be controlled and optimised thus improving the product. Measuring surface texture at the end of the cycle allows engineers to form an opinion on the component’s performance capability.

All manufactured surfaces depart from the desired ideal surface. This variation imparts various characteristics upon the component. The life of mating surfaces, such as shafts and bearings is dependent on surface texture. If a shaft is subject to reversals of load it can become fatigued and its life is reduced. Failure usually occurs at the root of any surface irregularity, therefore, the better the surface texture the longer will be the fatigue life.

The useful life of a product is governed by the rate of wear of its component parts, and the rate of this wear will depend on the surface areas in contact and the physical nature of the materials. A rough surface with large peaks will have less contact area and will wear more quickly than a smoother surface with small peaks.

A perfectly smooth surface is not a good bearing area, for example, seizure can occur due to the difficulty of ensuring that a lubricating film is maintained between the mating surfaces - metal to metal contact will cause rapid wear.

ISO 4287 is the International Standard that relates to the terms, definitions and surface texture parameters in current use. The standard defines the co-ordinate system in which surface texture parameters are defined. 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 **real surface** is defined as the surface limiting the body and separating it from the surrounding medium.

The **surface profile** results from the intersection of the real surface by a specified plane. It is usual to select a plane with a normal that nominally lies parallel to the real surface and in a suitable direction. ISO 13565-1 indicates that the traversing direction for assessment purposes shall be perpendicular to the direction of the lay unless otherwise indicated.

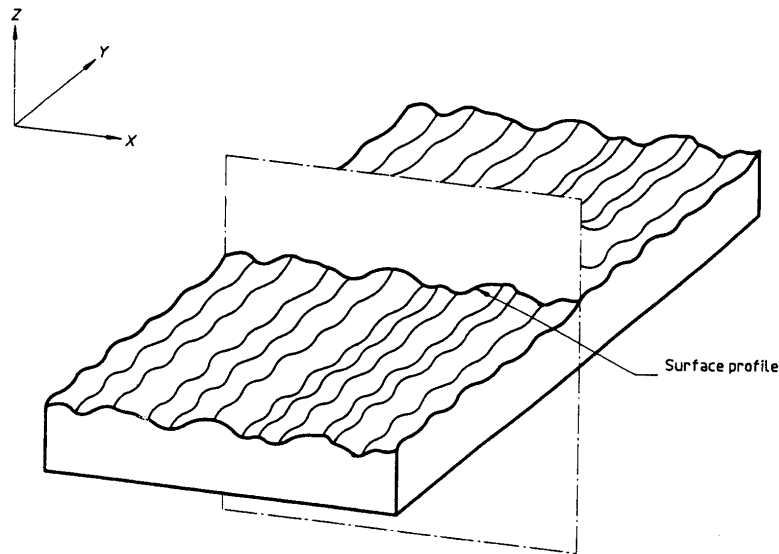


Figure 1 Co-ordinate system advocated by ISO 4287

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 is functionally significant it is important to specify this on an engineering drawing detailing the type of lay and the direction (see Appendix B or ISO 1302).

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. In some cases 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 may 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 will be 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.

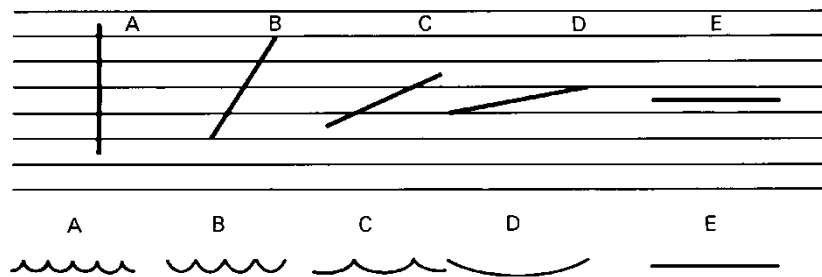


Figure 2 The effect of measuring in different directions to the surface lay, courtesy of Taylor Hobson Ltd.
Note that the direction of lay runs across the page

When measuring surface texture, care must be taken with the interpretation of the results; even two surfaces having the same surface texture parameter value can have different functional characteristics. The upper surface in figure 3 will have good wear characteristics while the lower surface, although having the same value for R_a (see section 3 for parameter descriptions) will wear more quickly due to the sharp spikes on the surface.

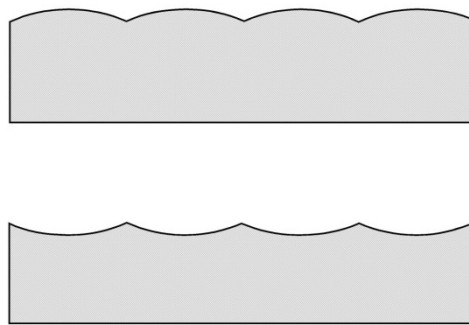


Figure 3 Two surfaces with the same R_a value but different functional characteristics

There are many methods for measuring surface texture that are commercially available today. This guide only considers the use of a stylus instrument to measure a surface profile, *i.e.* a two rather than a three dimensional measurement. The reason for the lack of coverage of other methods is that such methods are not covered in the profile standards. Guidance on the use of optical instruments is covered in other NPL good practice guides (see Appendix C). The guide also discusses the use of comparison specimens. The various standards relating to surface texture and referred to in the text are listed in Appendix C.

A typical stylus instrument

2

IN THIS CHAPTER

- Portable stylus instruments
- Chapter summary

ISO 3274 defines the various elements of a typical stylus instrument and figure 4 shows the interrelationship between the elements. Stylus instruments are by far the most common instruments for measuring surface texture today. A typical stylus instrument consists of a stylus that physically contacts the surface being measured and a transducer to convert its vertical movement into an electrical signal. Other components can be seen in Figure 4 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; a device, also driven at a constant speed, for recording the amplified signal or a computer that automates the data collection. Figures 5 and 6 are photographs of some typical commercial stylus instruments.

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 will not penetrate into valleys and will give a distorted or filtered measure of the surface texture. Consequently, certain parameters will be more affected by the stylus shape than others. The effect of the stylus forces can have a significant influence on the measurement results and if the force is too high damage may occur to the surface being measured. If the force is too low, the stylus will not stay reliably in contact with the surface.

To enable a true cross section of the surface to be measured, the stylus, as it is traversed across the surface, must follow an accurate reference path that has the general profile of, and is parallel to, the nominal surface. Such a datum may be developed by a mechanical slideway. The need for accurate alignment of the object being measured is eliminated by the surface datum device in which the surface acts as its own datum by supporting a large radius of curvature spherical (or sometimes with different radii of curvature in two orthogonal directions) skid fixed to the end of the hinged pick-up. At the front end of the pick-up body the skid rests on the specimen surface. Alternatively, a flat surface or shoe, freely pivoted so that it can align itself to the surface, may be used. Two skids may be used on either side of the stylus. It is worth noting that although ISO 3274 does not allow for the use of a skid and a new commercial instrument is unlikely to have one, they are still used in practice.

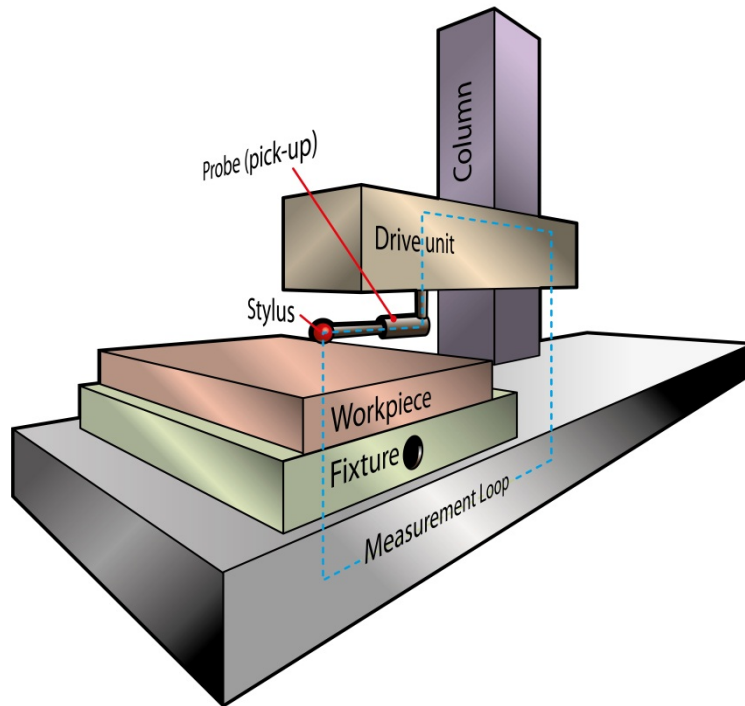


Figure 4 Elements of the typical stylus instrument, from ISO 3274

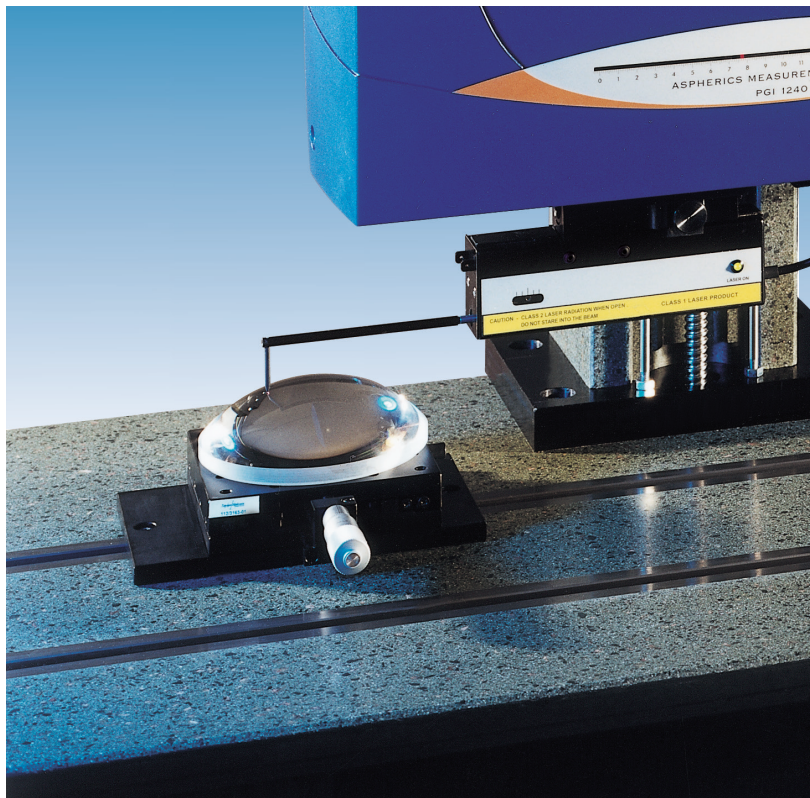


Figure 5 A typical tabletop stylus instrument, courtesy of Taylor Hobson Ltd



Figure 6 A typical tabletop stylus instrument, courtesy of Mitutoyo

Portable stylus instruments

The above description of a typical stylus instrument refers mainly to a tabletop instrument, *i.e.* an instrument that is not moved on a regular basis. Presently there are a number of commercially available portable instruments that can be mounted directly onto the surface being measured. Figures 7 and 8 show two such instruments. Whilst these instruments have a number of obvious advantages, the user should be aware of the disadvantages and limitations:

- Manufacturing conditions on the shop floor environment are likely to be uncontrolled leading to temperature gradients, dust, dirt and vibration. Care should be taken with results obtained under these conditions.

- Hand-held machines normally have fewer measurement parameters available to the user than tabletop instruments.
- The traverse length may be shorter than that of tabletop machines.



Figure 7 A typical portable instrument, courtesy of Taylor Hobson Ltd



Figure 8 A typical portable instrument, courtesy of Mitutoyo

Chapter summary

- Describes a simple stylus instrument for surface texture measurement.
- Presents both tabletop and portable stylus instruments.

The terms and definitions in use

3

IN THIS CHAPTER

- General terms
- Geometrical parameter terms
- Surface profile parameter definitions
- Spacing parameters
- Hybrid parameters
- Curves and related parameters
- Parameter overview
- Chapter summary

Prior to the 1990s, many variations in measurement practice, parameter definitions and terminology were proposed. As the subject of surface texture measurement has matured, International Standards have attempted to concentrate attention onto just a few of these. Unfortunately, one effect of this has been to introduce highly formal terms that are not essential to the accurate communication of data between users.

The international standard ISO 4287 specifies the terms, definitions and parameters to be used in the determination of surface texture by stylus methods. In order to distinguish between parameters in general use before the implementation of ISO 4287, Appendix A of this guide contains terms, definitions and parameters prior to the introduction of the current standard.

Care must be taken when quoting a numerical figure that represents surface texture, for example when a manufacturing engineer, a machinist and an inspector come into contact with the specification of a component, they do not necessarily know which parameter to follow. The engineer may write a specification based on an old or a new standard. The machinist may be working to an old or new drawing or technical specification document. The specification may have been produced in a design/development department operating under different national or international standards. Finally, the measuring instrument may incorporate any or all of a number of software algorithms under the same or different names. The potential for error is, therefore, considerable - users of measuring instruments should be aware of this and take all necessary steps to prevent measurements to the wrong standards taking place.

General terms used in surface texture

Most of the terms and definitions that follow are taken from ISO 4287. At first glance there appears to be a vast number of terms that one must master when interpreting and understanding surface texture measurement. The reader is advised to consider these definitions whilst using the actual instrument – this will help in becoming fluent in the language of surface texture.

In general, it can be stated that surface texture is what is left after the overall form of the surface has been removed, either mechanically or mathematically (or more usually both). For example, one may remove a straight line from the data to take out the influence of the sample being tilted with reference to the mounting table or if the sample is spherical one would remove a quadratic (second order) fit to take out the curvature in the surface. All instruments will have software options for removing the form of the surface. Once the form has been removed the surface texture is composed of three components that are defined according to the filters that are applied. The three components are known as profile, waviness and roughness and are described below. Once again, most instrument software will do the number crunching to filter that data, but the user must be aware of the required filter characteristics. Currently, the ISO specification standards do not lay down hard and fast mathematical rules for splitting the surface texture into profile, waviness and roughness, but these rules are being debated by the relevant committees.

Traced profile

The traced profile 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).

Reference profile

The reference profile is the trace that the probe would report as it is moved with the intersection plane along a perfectly smooth and flat workpiece. The reference profile 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.

Total profile

The total profile is the (digital) form of the profile reported by a real instrument, combining the traced profile and the reference profile. Note that in most instrument systems it is not practical to 'correct' for the error introduced by datum imperfections and the total profile is the only available information concerning the traced profile.

Filters and filtering

Filtering plays a fundamental role in surface texture analysis. In our context, it is any means (usually electronic or computational, but sometimes mechanical) for selecting for analysis a range of structure in the total profile that is judged to be that of significance to a particular situation. Alternatively, it may be thought of as a means of rejecting information considered irrelevant, including for example, attempts to reduce the effect of 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 frequencies. A **high pass** filter preserves the shorter wavelength features while rejecting longer ones. The combination of a low pass and 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 (rejection) of a filter should not be too sudden else we might get very different results 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 (note that this definition is specific to the field of surface texture).

For the great majority of surfaces it can be recommended that if a feature of a certain width is important, one of only say 1 % of the width is unlikely to be important. This suggests that **band pass** filtering should be employed in all surface texture analysis.

Profile filter

The profile filter is defined as the filter that separates profiles into long wave and short wave components (refer to figure 9).

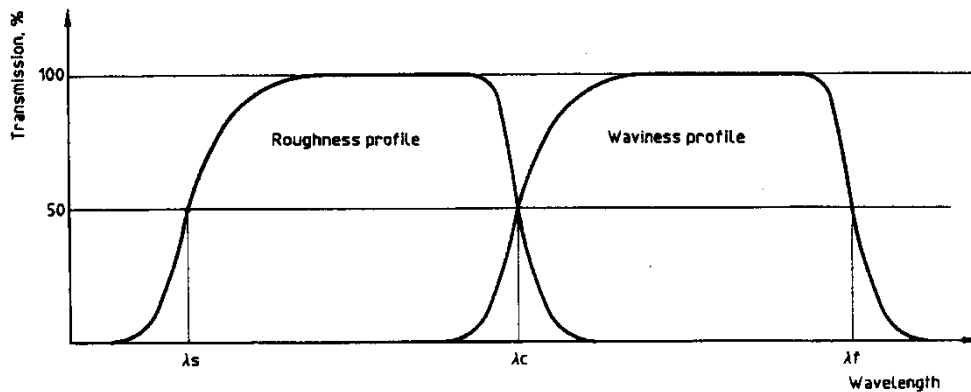


Figure 9 Separation of surface texture into roughness, waviness and profile, from ISO 4287

There are three filters used by instruments for measuring roughness, waviness and primary profiles.

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.

λ_c profile filter

This is the filter that defines where the intersection occurs between the roughness and waviness components.

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.

Primary profile

The primary profile is the basis for the evaluation of the primary profile parameters. It is defined as the total profile after application of the short wavelength (low pass) filter, with cut-off λ_s . Ultimately, the finite size of the stylus limits the rejection of very short wavelengths and in practice this mechanical filtering effect is often used by default for the λ_s filter. Since styli vary, and since the instrument will introduce vibration and other noise into the profile signal that has equivalent wavelengths shorter than the stylus dimensions, the best practice is always to ignore λ_s filtration upon the total profile. Figure 10 relates the primary to the roughness and waviness profiles.

Figure 10 Primary, waviness and roughness profiles



10a The primary profile is the profile used as the basis for the evaluation of the primary profile parameters. This profile represents the basis for digital processing by means of a profile filter and calculation of the profile parameters according to ISO 4287. It is characterised by the vertical and horizontal digital steps, courtesy of Mitutoyo.



10b The roughness profile illustrated is derived from the primary profile by suppression of the long wavelength component using the profile filter λ_c , courtesy of Mitutoyo.



10c The filtered waviness profile is derived by the application of the long wavelength profile filter λ_f and the short wavelength profile filter λ_c to the primary profile, courtesy of Mitutoyo.

Roughness profile

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

Waviness profile

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

Sampling length l_p , l_r , l_w

Sampling length is the length in the direction of the x axis used for identifying the irregularities that characterise the profile under evaluation. Specifying a sampling length implies that structure in a profile that occurs over greater lengths is not relevant to the particular evaluation. The sampling length for the primary profile l_p is equal to the evaluation length (see below). The sampling length for l_r (roughness) is numerically equal to the wavelength of the profile filter λ_c , the sampling length for l_w (waviness) is numerically equal to the wavelength of the profile filter λ_f . Almost all parameters should be evaluated over the sampling length, but it improves reliability to take an average of them from several sampling lengths (see evaluation length).

Evaluation length l_n

Evaluation length is the total length in the x axis used for the assessment of the profile under evaluation. It is normal practice to evaluate roughness and waviness profiles over several successive sampling lengths, the sum of which gives the evaluation length. For the primary profile the evaluation length is equal to the sampling length. ISO 4287 advocates the use of five sampling lengths as the default for roughness evaluation and if another number is used the assessment parameter will have that number included in its symbol, for example Ra_6 or Pt_2 . No default is specified for waviness. With a few exceptions, parameters should be evaluated in each successive sampling length and the resulting values averaged over all the sampling lengths in the evaluation length. Some parameters are assessed over the entire evaluation length. To allow for acceleration at the start of a measurement and deceleration at the end of a measurement, the instrument traverse length is normally rather longer than the evaluation length.

Total traverse length

Total traverse length is the total length of surface traversed in making a measurement. It is usually greater than the evaluation length due to the need to allow a short over travel at the start and end of the measurement to allow mechanical and electrical transients to be excluded from the measurement and to allow for the effects of edges on the filters.

Mean line for the roughness profile

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

Mean line for the waviness profile

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

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.

Geometrical parameter terms

All the parameters described below are calculated once the form has been removed from the measurement data. One must remember that not all the parameters are necessarily useful in all circumstances. For a given application the user must choose the appropriate parameters. In some circumstances, for example when a parameter is specified on an engineering drawing, the choice of parameter is not under the control of the instrument user. As with most areas of surface texture, the user must always be vigilant and seek to understand how a parameter is calculated and what it means.

The concepts of a peak and a valley are important in understanding and evaluating surfaces. Unfortunately, it is not always easy to decide what should be counted as a peak. For example, is it likely that all the peaks in the profile shown in Figure 11 are important? To overcome the confusion by early non-co-ordinated attempts to produce parameters reflecting this difference, the modern standards introduce an important specific concept: *the profile element consisting of a peak and a valley event*. Associated with the element is a discrimination that prevents small, unreliable measurement features from affecting the detection of elements.

Profile element

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).

Profile peak

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.

Profile valley

As for profile peak but with the direction reversed.

Discrimination level

It is possible a profile could have a very slight fluctuation that takes it across the mean line and almost immediately back again. This is not reasonably considered as a real profile peak or profile valley. To prevent automatic systems from counting such features, only features larger than a specified height and width are counted. In the absence of other specifications, the default levels are that the height of a profile peak (valley) must exceed 10 % of the R_z , W_z or P_z parameter (on maximum height of profile in chapter 3) value and that the width of the profile peak (valley) must exceed 1 % of the sampling length. Both criteria must be met simultaneously.

Ordinate value $Z(x)$

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

Profile peak height Z_p

This is the distance between the mean line on the x axis and the highest point of the highest profile peak (see figure 11).

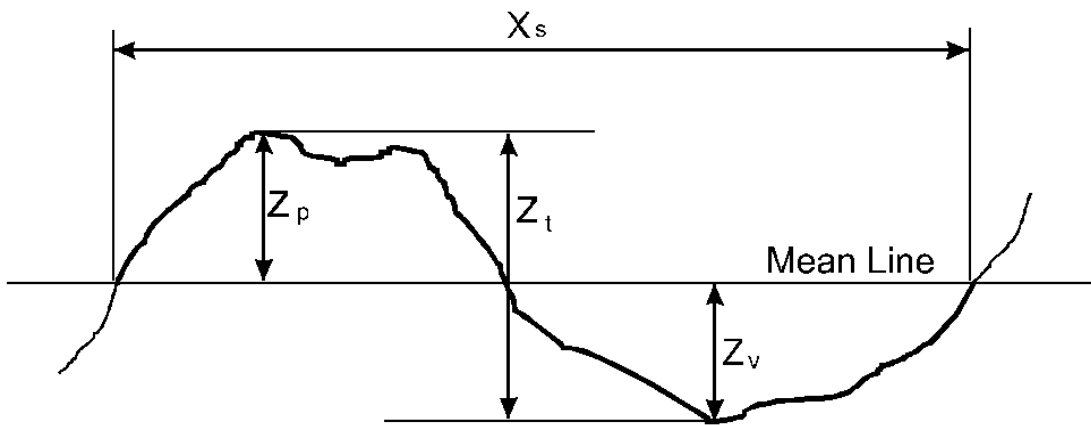


Figure 11 Profile element definitions, from ISO 4287

Profile valley depth Z_v

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

Profile element height Z_t

This is the sum of the height of the peak and depth of the valley of the profile element, *i.e.* the sum of Z_p and Z_v .

Local slope dZ/dX

This is the slope of the assessed profile at position x_i (see figure 12). The numerical value of the local slope, and thus the parameters $P\Delta q$, $R\Delta q$ and $W\Delta q$, depends critically on the ordinate spacing.

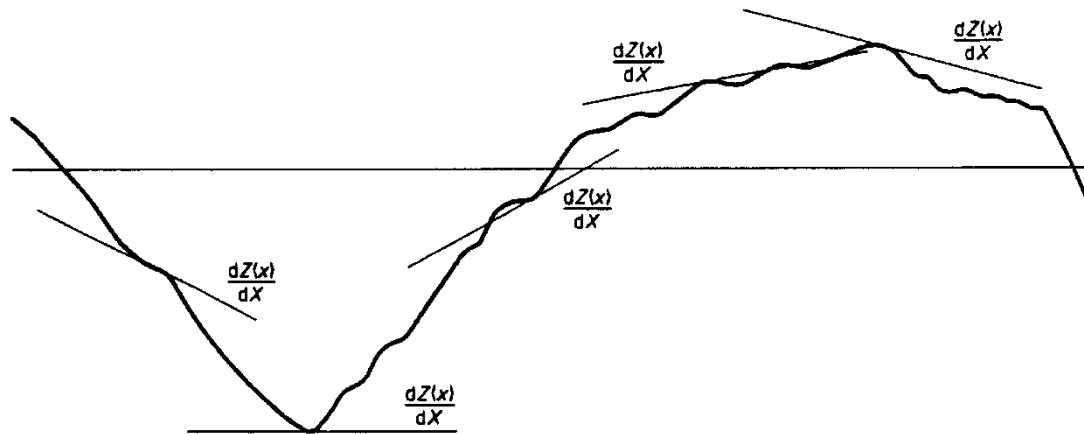


Figure 12 Definition of local slope, from ISO 4287

Surface profile parameter definitions

The parameters defined below 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.

Amplitude parameters (peak to valley)

Maximum profile peak height Pp , Rp , Wp

This parameter is the largest profile peak height Zp within the sampling length (see figure 13). This measure is the height of the highest point of the profile from the mean line. This parameter is often referred to an extreme-value parameter and as such can be unrepresentative of the surface as its numerical value may vary so much from sample to sample. It is possible to average over several consecutive sampling lengths and this will reduce the variation, but the value is often still numerically too large to be useful in most cases. However, this parameter will succeed in finding unusual conditions such as a sharp spike or burr on the surface, or the presence of cracks and scratches that may be indicative of poor material or poor processing.

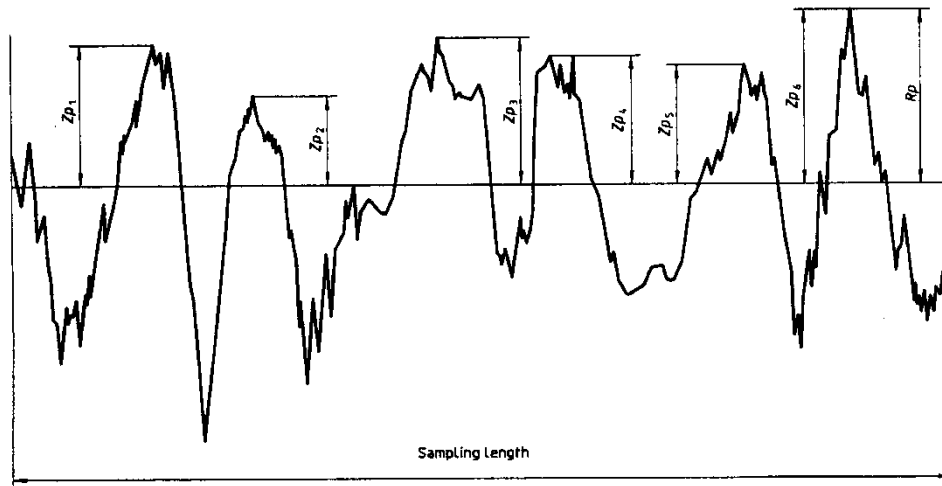


Figure 13 Maximum profile peak height, example of roughness profile, from ISO 4287

Maximum profile valley depth P_v , R_v , W_v

This is the largest profile valley depth Z_v within the sampling length (see figure 14). It is the depth of the lowest point on the profile from the mean line and is an extreme-value parameter with the same disadvantages as the maximum profile peak height.

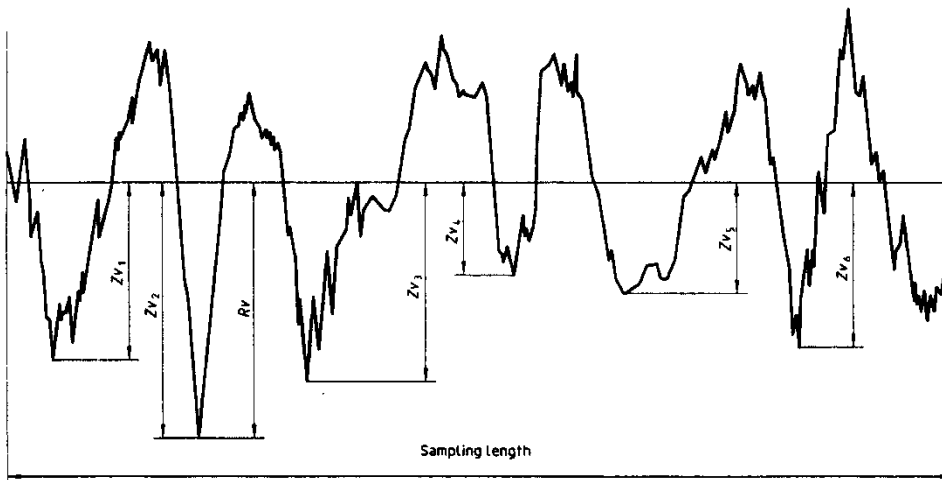


Figure 14 Maximum profile valley depth, example of roughness profile, from ISO 4287

Maximum height of profile P_z , R_z , W_z

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

Mean height of profile elements P_z , R_z , W_z

This is the mean value of the profile element heights Z_t within a sampling length (see figure 15). This parameter requires height and spacing discrimination as described earlier. If these values are not specified then the default height discrimination used shall be 10 % of P_z , R_z or W_z respectively. The default spacing discrimination shall be 1 % of the sampling length. Both of these conditions must be met. It is extremely rare to see this parameter used in practice and it can be difficult to interpret. It is described here for completeness and, until it is seen on an engineering drawing, should probably be ignored.

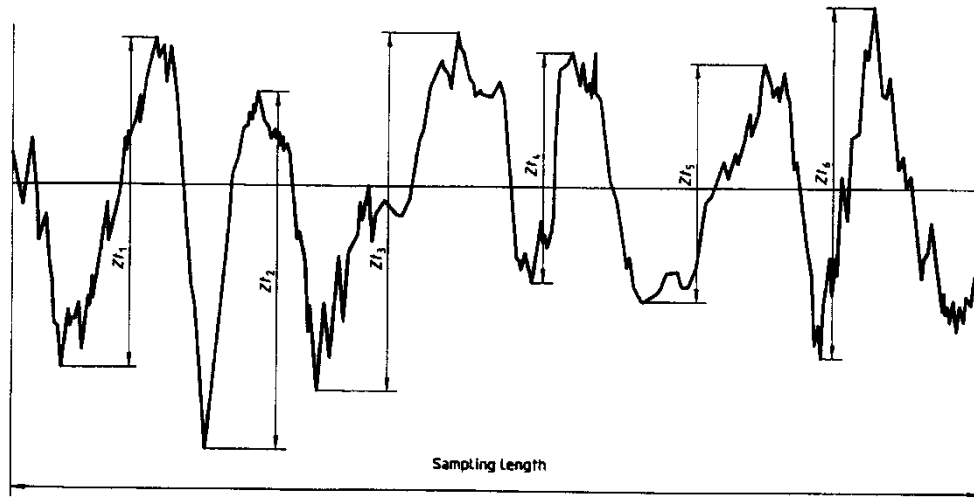


Figure 15 Height of profile elements, example of roughness profile, from ISO 4287

Total height of profile P_t , R_t , W_t

This is the sum of the height of the largest profile peak height Z_p and the largest profile valley depth within the evaluation length. This parameter is defined over the evaluation length rather than the sampling length and as such it has no averaging effect. Therefore, scratches or dirt on the surface can directly affect R_t .

Amplitude parameters (average of ordinates)

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

This is the arithmetic mean of the absolute ordinate values $Z(x)$ within the sampling length. The R_a of a surface can vary considerably without affecting the performance of the surface. It is usual, therefore, to specify on the drawing a tolerance band or a maximum R_a value that is acceptable. Expressed mathematically

$$R_a = \frac{1}{l} \int_0^l |z(x)| dx$$

Note that the above equation is for a continuous $z(x)$ function. However, when making surface texture measurements, $z(x)$ will be determined over a discrete number of measurement points. In this case, Ra should be written as

$$Ra = \frac{1}{N} \sum_{i=1}^N |Z_i|$$

where N is the number of measured points in a sampling length (see figure 17). The equations for the other profile parameters in this section, that involve an integral notation, can be converted to a summation notation in a similar manner.

The derivation of the Ra parameter can be illustrated graphically as shown in figure 16. The areas of the graph below centre line within the sampling length are placed above the centre line. The Ra value is the mean height of the resulting profile.

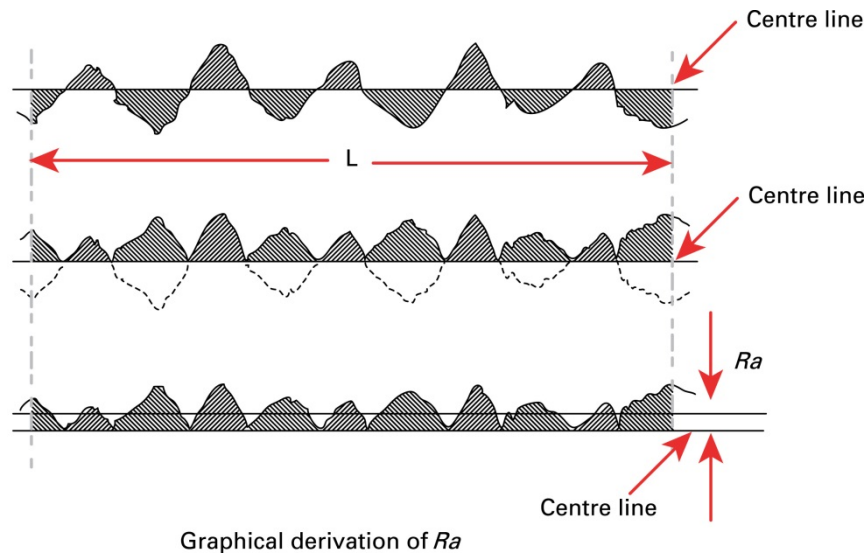


Figure 16 Derivation of the arithmetical mean deviation (from Leach R K 2009 *Fundamental Principles of Engineering Nanometrology* (Elsevier: Amsterdam))

The Ra value over one sampling length is the average roughness, therefore, the effect of a single non-typical peak or valley will have only a slight influence on the value. It is good practice to make assessments of Ra over a number of consecutive sampling lengths and to accept the average of the values obtained. This will ensure that Ra is typical of the surface under inspection. It is important that measurements take place perpendicular to the lay. The Ra value does not provide any information as to 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. For historical reasons, Ra is probably the most common of all the surface texture parameters. This should not deter users from considering other parameters that may give more information regarding the functionality of a surface.

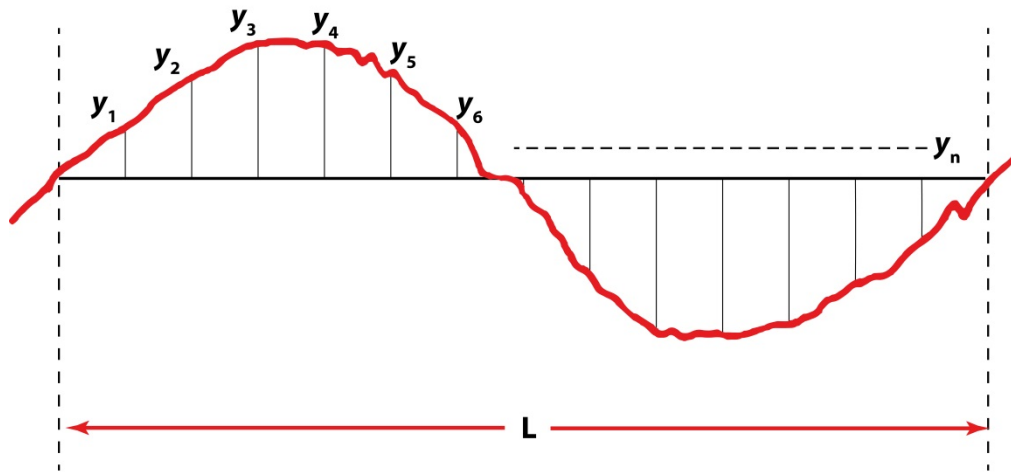
Root mean square deviation from the assessed profile Pq , Rq , Wq

This is the root mean square value of the ordinate values $Z(x)$ within the sampling length and expressed mathematically

$$Rq = \sqrt{\frac{1}{N} \sum_{i=1}^N Z_i^2}.$$

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 17 illustrates how Ra and Rq are determined from the profile.



Mathematical derivation of Ra and Rq

$$Ra = \frac{|y_1| + |y_2| + \dots + |y_n|}{n}$$

$$Rq = \sqrt{\frac{y_1^2 + y_2^2 + y_3^2 + \dots + y_n^2}{n}}$$

Figure 17 Determination of Ra and Rq , courtesy of Taylor Hobson Ltd

The reason for the commonality of Ra and Rq is chiefly historical. Ra is easier to determine graphically from a recording of the profile and was, therefore, adopted initially before automatic surface texture measuring instruments became generally available. When roughness parameters are determined instrumentally Rq has the advantage that phase effects from electrical filters can be neglected. 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 more directly related to the optical quality of a surface.

Skewness of the assessed profile Psk , Rsk , Wsk

Skewness is the quotient of the mean cube value of the ordinate values $Z(x)$ and the cube of Pq , Rq or Wq respectively within the sampling length (see figure 18). 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 if the profile spikes are evenly distributed above or below the line and is strongly influenced by isolated peaks or isolated valleys. Expressed mathematically

$$Rsk = \frac{1}{Rq^3} \left[\frac{1}{N} \sum_{i=1}^N Z_i^3 \right]$$

This parameter represents the degree of bias, either in the upward or downward direction, of an amplitude distribution curve. The shape of the curve is very informative. A symmetrical profile gives an amplitude distribution curve, which is symmetrical about the centre line and 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.

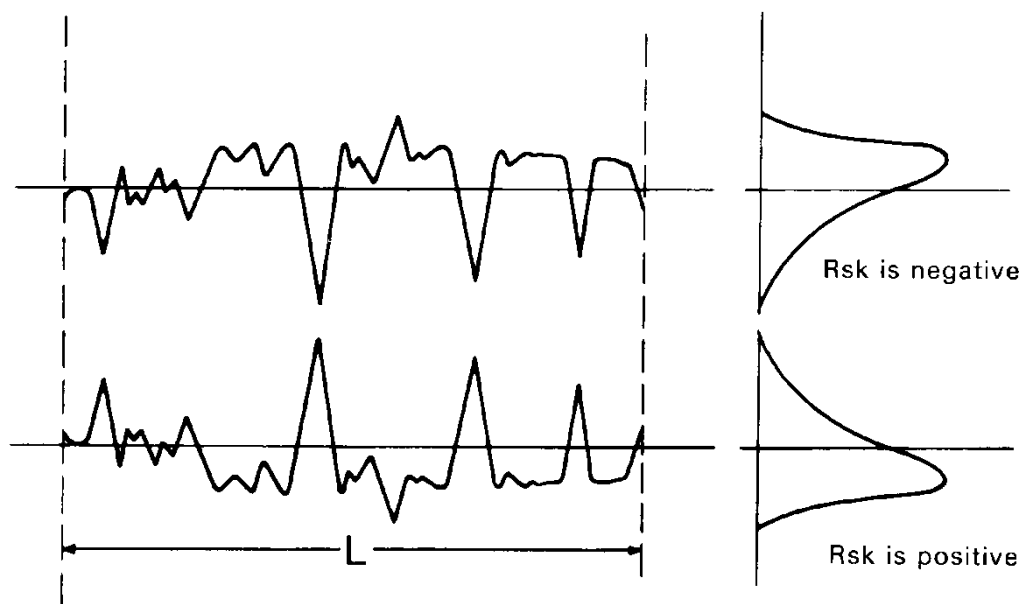


Figure 18 The difference between positive and negative skewness, courtesy of Taylor Hobson Ltd

As an example, a porous, sintered or cast iron surface will have a large value of skewness. A characteristic of a good bearing surface is that it should have 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.

Kurtosis of the assessed profile Pku , Rku , Wku

This is the quotient of the mean quartic value of the ordinate values $Z(x)$ 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 will have a high kurtosis value and a bumpy surface will have a low kurtosis value. This is a useful parameter in predicting component performance with respect to wear and lubrication retention. Note that kurtosis cannot tell the difference between a peak and a valley. Expressed mathematically

$$Rku = \frac{1}{Rq^4} \left[\frac{1}{N} \sum_{i=1}^N Z_i^4 \right].$$

Spacing parameters

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 19). In other words, this parameter 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. If these values are not specified then the default height discrimination used shall be 10 % of Pz , Rz , Wz respectively. The default spacing discrimination shall be 1 % of the sampling length. Both of these conditions must be met.

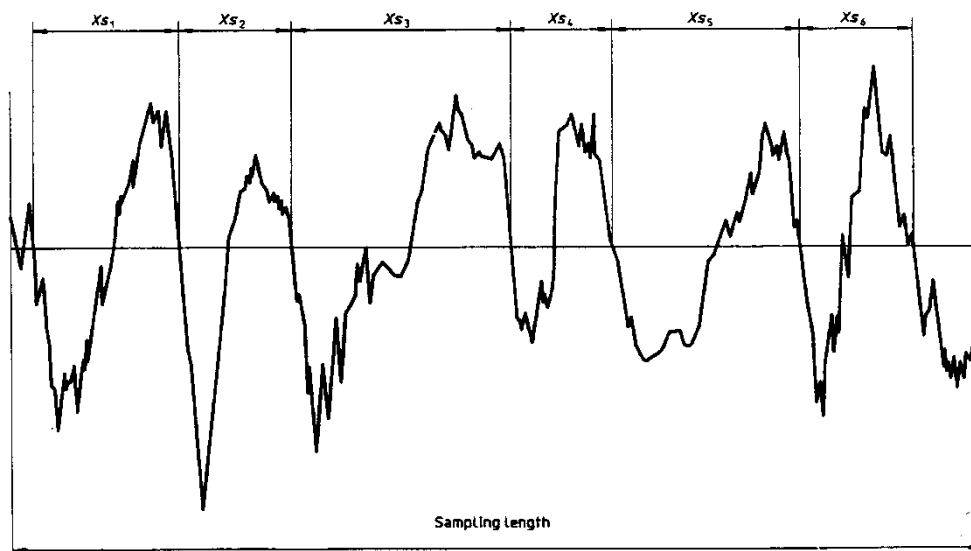


Figure 19 Width of profile elements, from ISO 4287

Peak count number PPc , RPc , WPc

This parameter is the number of mean widths of the profile elements (PSm , RSm , WSm) in a reference length, L ,

$$RPc = \frac{L}{RSm}.$$

A reference length of 10 mm is recommended if not otherwise stated. A height discrimination threshold of RSm of $\pm 0.5 \mu\text{m}$ is recommended.

Hybrid parameters

Root mean square slope of the assessed profile $P\Delta q$, $R\Delta q$, $W\Delta q$

This is the root mean square value of the ordinate slopes dZ/dX 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. An 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. This parameter is useful in painting and plating applications where the length of surface is important for keying. Average slope can also be related to hardness, elasticity and ‘crushability’ of the surface and in optical applications a small value is an indication that the surface is a good optical reflector.

Curves and related parameters

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

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.

Material ratio of the profile (Abbot-Firestone or Bearing Ratio Curve)

This ratio 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 be easily seen and provides a means of distinguishing different shapes present on the profile. The definition of the bearing area fraction, is the sum of the lengths of individual plateaux at a particular height, normalised by the total assessment length, and is the parameter designated Rmr (see Figure 20). 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 will remove the peaks of the original process but the deep valleys will be left untouched. This process leads to a type of surface texture that is referred to as a stratified surface. The height distributions will be negatively skewed therefore making it difficult for a single average parameter such as R_a to represent the surface effectively for specification and quality control purposes.

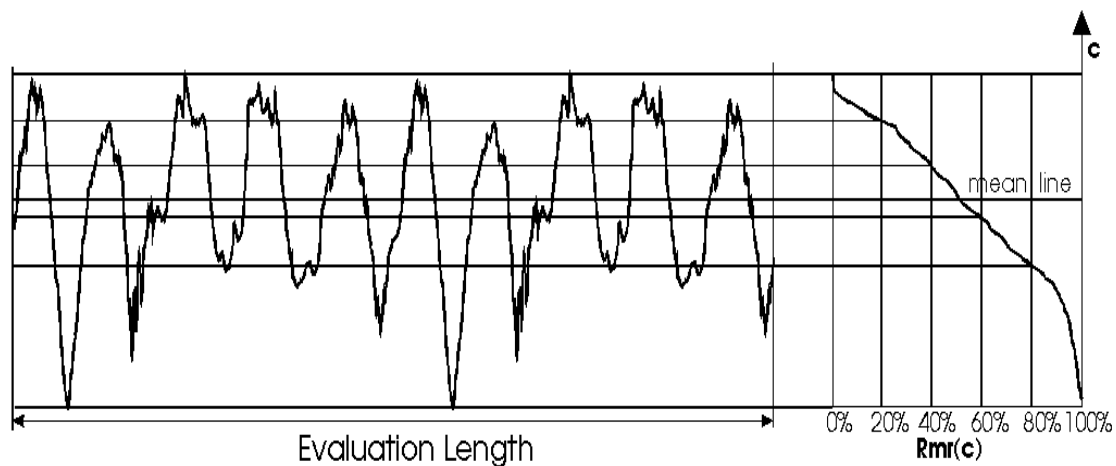


Figure 20 Material ratio curve, from ISO 4287

Profile section height difference $P\delta_c$, $R\delta_c$, $W\delta_c$

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

Relative material ratio Pmr , Rmr , Wmr

This is the material ratio determined at a profile section level $R\delta_c$, and related to a reference C_0 , where

$$C_1 = C_0 - R\delta_c \text{ (or } P\delta_c, \text{ or } W\delta_c)$$

$$C_0 = C(Pmr_0, Rmr_0, Wmr_0).$$

Rmr refers to the bearing ratio at a specified height (see figure 21). A 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 - 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.

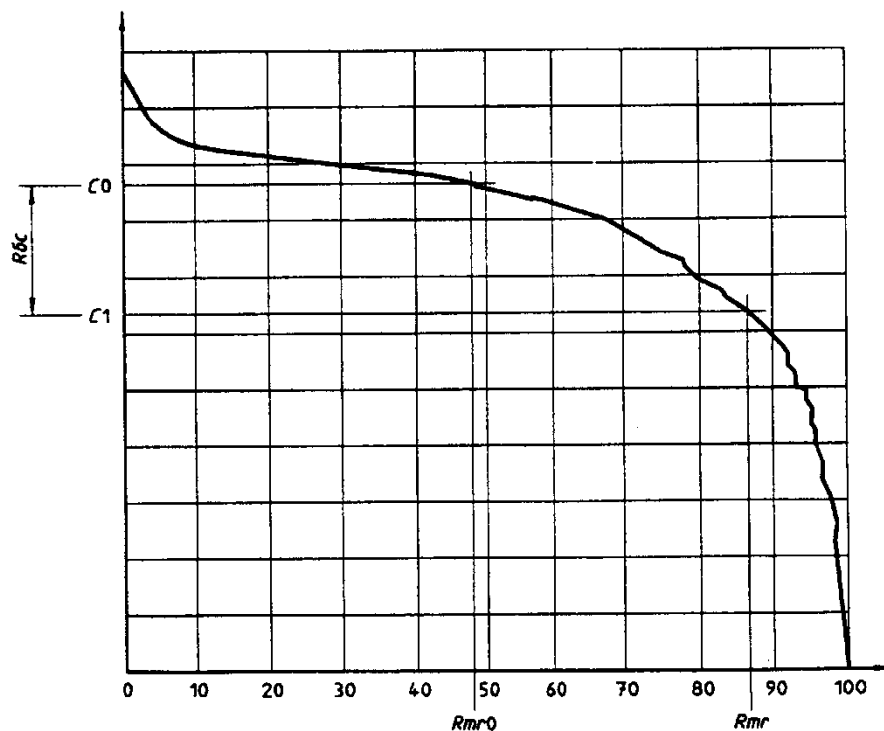


Figure 21 Profile section level separation, from ISO 4287

Profile height amplitude curve

The profile height amplitude curve 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 like many probability distributions (see figure 22). The curve tells the user how much of the profile lies at a particular height, in a histogram sense.

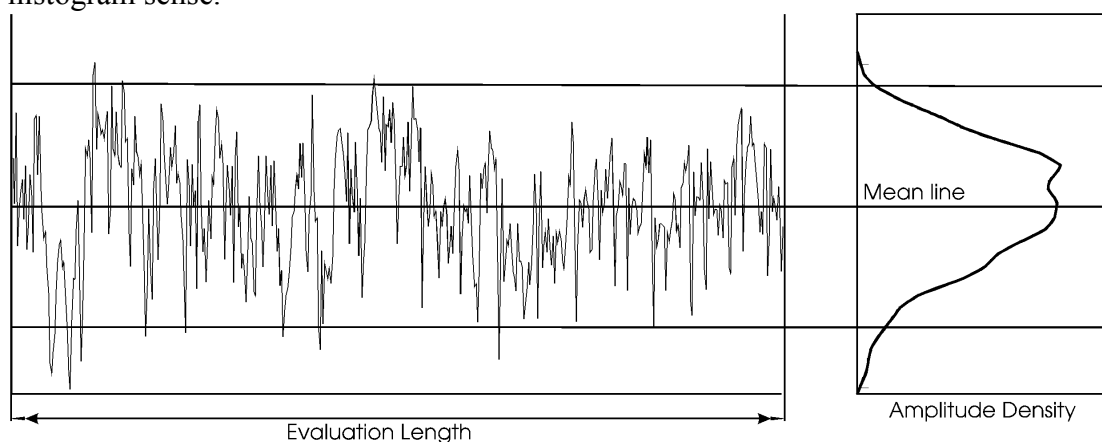


Figure 22 Profile height amplitude distribution curve, from ISO 4287

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. This is illustrated in figure 23. 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.

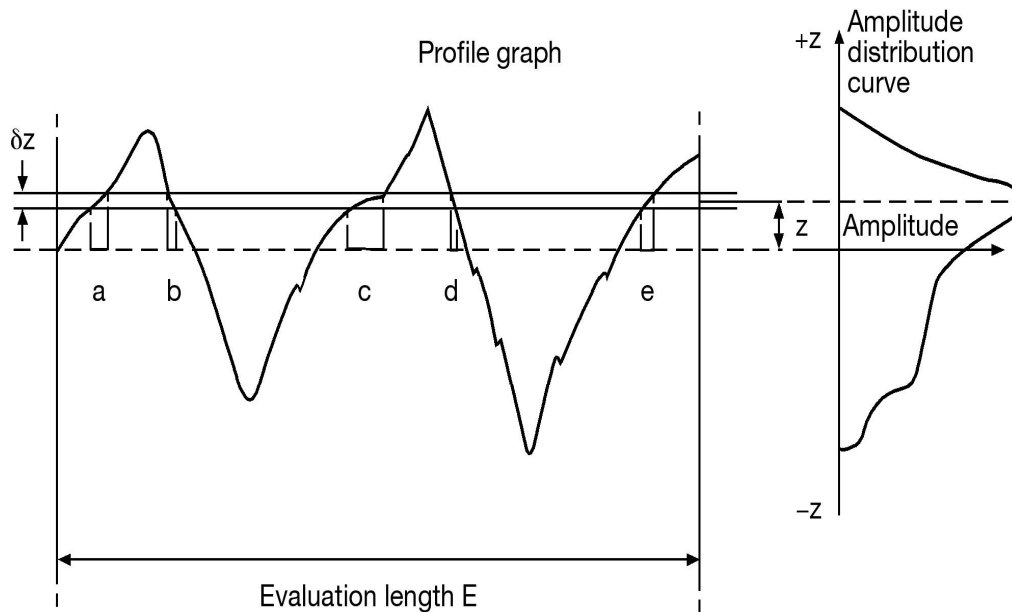


Figure 23 Amplitude distribution curve

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.

Parameter overview

Table 1 summarises the range of surface texture parameters discussed in this section and indicates whether the parameter is calculated over a sampling length or the evaluation length.

Parameters 1997 edition	1984 edition	1997 edition	Determined within	
			Evaluation length	Sampling Length
Maximum profile height	R_p	R_p		×
Maximum profile valley depth	R_m	R_v		×
Maximum height of profile	R_y	R_z		×
Mean height of profile	R_c	R_c		×
Total height of profile	-	R_t	×	
Arithmetical mean deviation of the assessed profile	R_a	R_a		×
Root mean square deviation of the assessed profile	R_q	R_q		×
Skewness of the assessed profile	S_k	R_{sk}		×
Kurtosis of the assessed profile	-	R_{ku}		×
Mean width of profile elements	S_m	R_{Sm}		×
Root mean square slope of the assessed profile	Δq	$R_{\Delta q}$		×
Material ratio of the profile		$R_{mr(c)}$	×	
Profile section height difference	-	$R_{\delta c}$	×	
Relative material ratio	tp	R_{mr}	×	
Ten point height (deleted as an ISO parameter)	R_z	-		

Table 1 Old and new surface texture parameters, ISO 4287

Chapter summary

- Presents general terms, filters, and geometrical parameter terms and definitions.
- Presents curves and related parameters.
- Parameter overview.

Measurement preparation and instrument set up

4

IN THIS CHAPTER

- Environmental conditions
- Preparation for measurement
- Stylus size and shape
- Choice of cut-off wavelength (sampling length) and filters
- Choice of measuring speed

To obtain the best possible performance from a surface texture measuring instrument it should be used in a safe and stable environment.

Environmental conditions

The instrument should be used in an environment that is as free as possible from dust, vibration and direct sunlight. Observe the conditions listed below.

- Select a location where the ambient temperature is maintained in the range $20\text{ }^{\circ}\text{C} \pm 10\text{ }^{\circ}\text{C}$ (with a condensation-free humidity of less than 85 % relative humidity).
- Store the instrument in a location where the temperature does not go outside the range $-10\text{ }^{\circ}\text{C}$ to $60\text{ }^{\circ}\text{C}$.
- Wipe any mist and dust from the workpiece surface prior to measurement using a lint free cloth.
- Remove any gross contamination from the surface, preferably by blowing the surface with filtered air.
- Remove any oil or grease from the surface using a suitable solvent.

Preparation for measurement

The electrical unit should be switched on at least one hour before any measurements take place - this will allow time for the instrument to stabilise (the manufacturer's instructions will normally specify a minimum stabilisation time for a given instrument). Calibration of the instrument is essential prior to measurement (see chapter 7). Before calibration of the instrument takes place, the stylus should be visually checked for signs of wear or damage and the user should ensure that the workpiece is free of dust or dirt by using an appropriate cleaning method. Visual examination of a $2\text{ }\mu\text{m}$ tip stylus may not be possible without the aid of specialised instrumentation such as a scanning electron microscope (see section on stylus and shape in chapter 4 and on Type B artefacts in chapter 7 for information on checking the stylus condition). In some cases chemical cleaning is preferable to the use of lint free cloth; if the surface texture is coarse then the cloth may deposit fabric on the surface that will affect the reading.

After measurement of the calibration artefact the indicated value should be compared with the value attached to the test specimen. If the measured value differs from the value that is shown on the calibration certificate then re-calibration is required. Depending on the instrument used, this adjustment can be carried out in a number of ways. Some 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 instruments that are software or processor based, the sensitivity of the instrument is automatically calibrated by entering the value shown on the calibration certificate into the machine display as prompted.

Stylus size and shape

The stylus is the only active component in contact with the surface being measured (possibly with exception of a skid). It is important that its dimension and shape are chosen appropriately - it is these features that will 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 or 10 µm (truncated pyramidal, or chisel, shaped, 0.1 µm tips are available for specialised measurements). Choice of stylus radius should be made by consulting table 2. The static measuring force at the mean position of the stylus should be 0.75 mN, according to ISO 3274, and should not change during the measurement. The manufacturer of the instrument generally sets this force. Where there is concern about the force value, it is possible to load the stylus onto a suitable pan-balance. In practice the tip is subject to wear, or more usually, breakage. A damaged stylus tip can lead to serious errors and the condition of the tip should be checked on a regular basis.

When checking the condition of the stylus, the user is advised to maintain historical records of the instrument reading for a chosen surface texture parameter (usually R_a) against the value for the calibration artefact quoted on its calibration certificate. (Chapter 7 describes the various tip condition artefacts that are advocated by ISO 5436-1). If there is a 10 % difference in the value obtained when compared to the historical data, the user should be alerted to the fact that there may 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:

(a) Penetration into valleys

On surfaces with deep, narrow valleys the stylus may not be able to penetrate fully to the bottom (see figure 24). The larger the tip radius the less the penetration, therefore, the value of a roughness height parameter will be smaller than the true value.

(b) Distortion of the peak shape

When a spherical stylus passes over a peak, the point of contact moves across the stylus. The effect on the stylus is to follow a path that is more rounded than the peak (see figure 24). As the stylus is raised to its full height when it makes contact with the crest, the true peak height is measured.

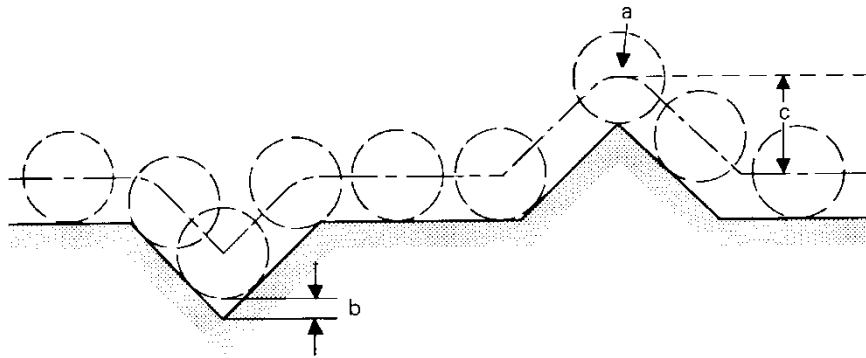


Figure 24 Effects of a finite stylus shape, courtesy of Taylor-Hobson Ltd

With reference to figure 23, the following effects can occur:

- a) the curvature tends to round off peaks;
- b) reduce the depths of valleys; and
- c) the peak height is unaffected.

(c) Re-entrant features

Since the stylus detects the surface by, in effect, moving downwards from above, it can never detect a re-entrant feature such as that shown in figure 25. Instead, it reports a simpler non-re-entrant profile as the stylus slides over the feature to make contact with the next flank.

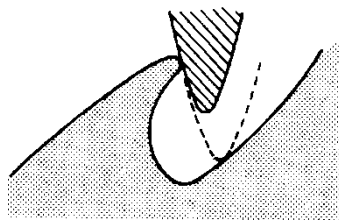


Figure 25 Example of a re-entrant feature, courtesy of Taylor-Hobson Ltd

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

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. When the sampling length is indicated on the drawing or documentation then the cut-off wavelength, λ_c , should be chosen to be equal to this sampling length. Table 2 shows the relationship between cut-off wavelength, tip radius and maximum sampling spacing.

λ_c /mm	λ_s /μm	Roughness cut-off wavelength ratio λ_c/λ_s	r_{tip} max /μm	Maximum sampling spacing /μm
0.08	2.5	30	2	0.5
0.25	2.5	100	2	0.5
0.8	2.5	300	2	0.5
2.5	8	300	5	1.5
8	25	300	10	5

Table 2 Relationship between the roughness cut-off wavelength λ_c , tip radius and maximum sampling spacing, from ISO 3274

When a component is manufactured from a drawing, the surface texture specification will normally include 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 will require a means of selecting the most appropriate value for his particular application. The sampling length should only be selected after considering the nature of the surface texture and which characteristics are required for the measurement. From Table 3 below it can be seen that a value of 0.8 mm could be used for nearly all of the machined surfaces. However, consideration must be given to the fact that this value may not be suitable for assessing a particular feature of the surface texture and that the function of the surface and the precision of the machining process must be taken into account.

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

Table 3 Choice of cut-off wavelength for a number of common machining operations

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 attenuate (remove) wavelength components of the surface outside the range of interest of the user.

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

On instruments that have a variable measuring speed, it is necessary to select the measuring speed appropriate for the electrical filter used, in order to ensure the specified cut-off is obtained. It is possible for various sampling lengths to be obtained by the use of a single filter in conjunction with the selection of different measuring speeds, but for practical reasons this method it is not often used.

A roughness filter is often used when measuring surfaces for characteristics related to 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, it is this feature of a surface that defines how it looks, feels and behaves in contact with another surface.

A waviness filter is used to determine the effects of machine tool performance and also types of component performance such as noise and vibration, that is to say the filter removes profile and roughness. Waviness is also important in some optical applications.

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 is generally parallel to the chart co-ordinates.

Filters have been standardised to give a percentage transmission, X %, at the cut-off. This results in the amplitudes of the irregularities having a spacing equal to the cut-off length being reduced to X % of their true value. The amplitudes of shorter wavelength irregularities will be unchanged, while those of the longer wavelength will be progressively reduced. In normal applications this will not significantly affect the value of a surface texture parameter.

Surfaces having finely finished plateaux with deep valleys can have a reference line that is undesirably influenced by the presence of the valleys. Filtering can suppress the valley influence and produce a reference line that is more appropriate to the analysis of the surface texture parameters of such artefacts.

The filtering process can be carried out in several stages. For example, the deep valleys shown in figure 26 can distort the measurement by causing the filter mean line not to follow the natural trend of the surface texture. The first mean line is determined by a preliminary filtering of the primary profile, using the phase corrected filter and a cut-off wavelength of

λc . All valley portions that lie below the mean line shown hatched in figure 26 are removed. The primary profile is replaced by the curve of the mean line. The same filter is again used on the profile with the valleys suppressed; the second mean line obtained is now the reference line relative to which the assessment of profile parameters is performed. This reference line is transferred to the original primary profile and the roughness profile can now be obtained from the difference between the primary profile and the superimposed reference line. The above example simply illustrates the possible complexities that can arise when considering filters. This degree of complexity is not found in most situations.

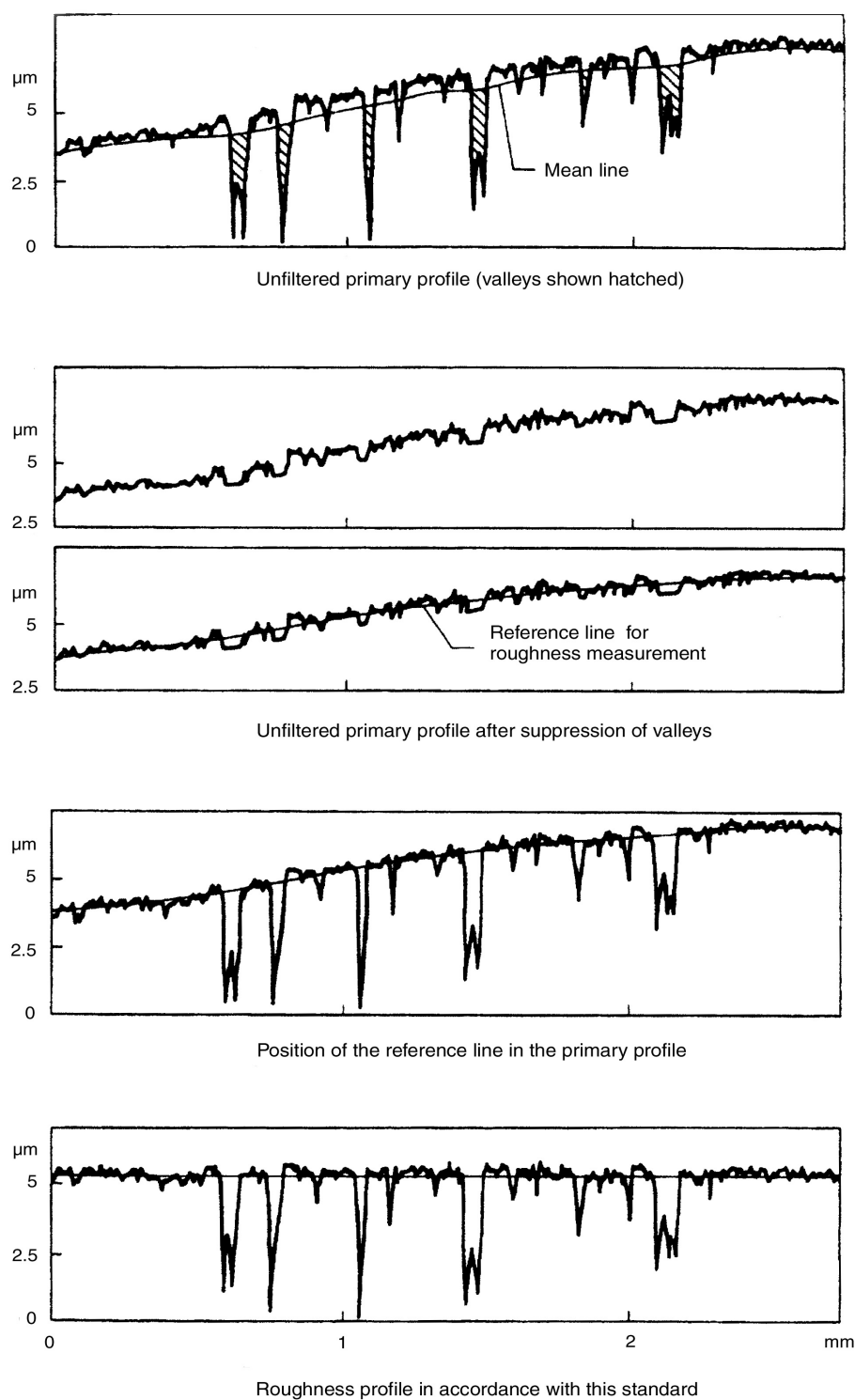


Figure 26 A typical filtering process, from ISO 13565

Choice of measuring speed

Modern surface texture measuring instruments allow a range of speeds to suit different applications. A pick-up traversing at a measuring speed of 1 mm s^{-1} 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 1 s). By halving the measuring speed to 0.5 mm s^{-1} , the frequency will be halved, and by increasing the measuring speed to 2 mm s^{-1} , the frequency will double. The maximum frequency to be handled can, therefore, be brought within the bandwidth of the system by selecting an appropriate maximum measuring speed. It is worth noting that on a lot of surface texture measuring instruments (especially older models) the measuring speed is fixed by the manufacturer and the end user has no control over this parameter. The bandwidth of the signal amplifier is always greater than that of the recorder; therefore, this factor can be ignored. However, the amplifier frequency response can be modified by the use of a filter, for example, to separate roughness from waviness, so that the filter bandwidth must be taken into account when calculating the maximum allowable measuring speed.

Chapter summary

- Discusses the importance of environmental conditions.
- Discusses preparation for measurement.
- How to choose stylus size and shape.
- How to choose the cut-off wavelength (sampling length) and filters.
- How to determine the measurement speed.

Measuring surface texture using comparison specimens

5

IN THIS CHAPTER

- Comparison specimens

As well as direct methods for measuring surface texture, such as by using a stylus instrument, there are also less accurate but simple and convenient comparative methods that can be used. The comparative methods are attempts to assess the surface by means of observation and/or feel of the surface. Caution is required when using comparison artefacts as the result is subjective - different results for the same surface may be obtained by different users.

Comparison specimens

A standard set of comparison specimens consists of a wallet containing a number of specimens covering example surface textures produced by various machining operations - turning, milling (horizontal and vertical), grinding, lapping and reaming. This range of finishes enables the user to compare his machined component with regard to feel and appearance with that of the corresponding comparison specimen produced by the same production process. Figure 27 is a photograph of a set of commercially available comparison specimens.



Figure 27 A standard set of comparison specimens, courtesy of Rubert + Co.

Advantages of comparison specimens

- Superior to visual examination alone.
- Does not require skill in setting up and operating an electronic instrument.
- Portable.
- Fast and simple check.

Disadvantages of comparison specimens

- Subjectivity - individuals may obtain different readings for the same component.
- Practice and skill is required in maintaining consistent results.

Note that, if the surface of a part is to be specified for a given application it is essential, after assessment using a comparison standard the surface must be given a numerical value. This should be done by using appropriate equipment that can achieve direct measurement of the surface texture.

Chapter summary

- Discusses the use of comparison specimens.

Making measurements and interpreting the results

6

IN THIS CHAPTER

- The 16 % rule and its application
- When to use the max-rule
- Selecting a cut-off wavelength

The workpiece should be located on the instrument base when using tabletop machines or on an appropriate surface if using a portable instrument. This step may require the user to use some form of clamping mechanism on the workpiece. In general, for heavy objects no clamping is required but, where the workpiece is small and light and likely to move when measured, the use of clamps or a vice is recommended. Care should be taken to ensure that the clamping forces do not distort the workpiece. In some cases the use of waxes, plastercine or double-sided sticky tape are alternatives to clamping. The use of restraining materials that are elastic by nature should be avoided due to the possibility of movement occurring while measurement takes place.

The workpiece should now be aligned to the traverse direction of the measuring stylus within the working range of the instrument. With hand held 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. In some cases, levelling a workpiece for measurement at high magnification requires considerable skill and can be time consuming. Manufacturers can supply auto-levelling tables that allow automatic adjustments to be made quickly and easily. However, auto-levelling requires a reasonable degree of initial levelling to get enough of the scan in range. Using auto-levelling devices requires a preliminary measurement to take place after which the table will adjust without intervention from the user. If the machine is software based and contains the appropriate algorithms, adjustment may be mathematically corrected by the tilt compensation function. It should be noted that the measurement of the workpiece cannot be made if the level of the workpiece is not within the instrument range.

The next stage is for the user to select the parameters (sampling length, speed, *etc.*) required for measurement. This selection will depend on the type and manufacture of the instrument and reference should be made to the appropriate operating manual.

Usually, at least ten measurements should be made. Measurement areas should be selected to be typical of the surface as a whole. Areas where there are obvious holes, scratches or other machining damage should be avoided. This issue is a particular problem when measuring the surfaces of ceramics.

The measurement traverse can then be made. On computer-based instruments, it may be possible to specify files and parameters to be applied to a profile after it has been measured. In this case it is still necessary to consider their specification before measurement in order to get 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 instrument. They will normally take the form of a trace, a printout of results or a file held in computer memory.

Under visual examination of the workpiece it will 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 should not be considered during surface texture inspection. If 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. If the surface texture is markedly different over the workpieces, then parameter values determined over each area must 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 will be used for comparison.

The 16 % rule and its application

Where the requirements specify an 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 a lower limit of the 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.

When to use the max-rule

Where the requirements specify a maximum value of the 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, R_{zmax}).

Selecting a cut-off wavelength

Where the sampling length is specified on the drawing, the cut-off length wavelength λ_c is chosen equal to the sampling length. Where a sampling length is not specified then the procedures detailed below should be used.

Procedure for non-periodic roughness profile

This group of surfaces may cause problems in obtaining meaningful roughness measurements. The surface has no repetitive structure and includes cast components, sintered and porous materials and sandblasted items. All of these surfaces are characterised 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:

1. Estimate the unknown roughness profile parameter for example, R_a , R_z , by visual inspection, use of roughness comparisons or graphical analysis of a profile trace or a primary profile (unfiltered) measurement.
2. Tables 4 and 5 show values of sampling length typically associated with different bands of R_a and R_z values. Select the sampling length corresponding to the parameter estimated in step 1.

3. Using a measuring instrument, obtain a representative measurement of the chosen parameter using the sampling length specified in step 2.
4. Compare the measured parameter value from step 3 with the range of values given in tables 4 and 5 for the sampling length used. If the measured parameter value lies within the range of values for the sampling length used, go to step 7.
5. If the measured parameter value lies outside the range of values for the sampling length used, adjust the instrument to the higher or lower sampling length indicated by the value measured in step 3.
6. Make a new parameter measurement at the adjusted setting. This value should now lie in the range for the sampling length used as specified in table 4 or 5. If it does not, go back to step 5.
7. Make a representative measurement of the roughness parameter by using the next smaller sampling length. (Depending on the action taken at step 5, the measurement from step 3 might already provide this information).
8. Check to see if the combination of roughness parameter and sampling length from step 7 corresponds to that which is specified in table 4 or 5.
9. If only the acceptable setting from step 3 or the final setting from step 6 (in the case where steps 5 and 6 were carried out) provides a parameter value and sampling length that are consistent with tables 4 or 5 (while step 7 provides an inconsistent combination), then both the sampling length selection and parameter value indication from step 3 or step 6 respectively are correct.
10. If the measurement at step 7 also provides a consistent combination of parameter value and sampling length as specified in tables 4 or 5, then this shorter sampling length and corresponding parameter value are correct.
11. The correct sampling length is now established by step 9 and step 10. Further representative measurements of selected parameters should be made using this cut-off wavelength (sampling length).

Ra / μm	Roughness sampling length l_r /mm	Roughness evaluation length l_n /mm
$(0.006) < Ra \leq 0.02$	0.08	0.4
$0.02 < Ra \leq 0.1$	0.25	1.25
$0.1 < Ra \leq 2$	0.8	4
$2 < Ra \leq 10$	2.5	12.5
$10 < Ra \leq 80$	8	40

Table 4 Estimates for choosing roughness sampling lengths for the measurement of non-periodic profiles, ISO 4288

Rz $Rz1\max$ $/\mu m$	Roughness sampling length l_r $/mm$	Roughness evaluation length l_n $/mm$
$(0.025) < Rz\ Rz1\max \leq 0.1$	0.08	0.4
$0.1 < Rz\ Rz1\max \leq 0.5$	0.25	1.25
$0.5 < Rz\ Rz1\max \leq 10$	0.8	4
$10 < Rz\ Rz1\max \leq 50$	2.5	12.5
$50 < Rz\ Rz1\max \leq 200$	8	40
Rz is used when measuring Rz , Rv , Rp , Rc and Rt $Rz1\max$ is used only when measuring $Rz1\max$, $Rv1\max$, $Pr1\max$ and $Rc1\max$		

Table 5 Estimates for choosing roughness sampling lengths for the measurement of non-periodic profiles, ISO 4288

Procedure for periodic roughness profile

A periodic surface is one that has a structure that repeats at a given spatial frequency, for example a turned surface. Even ground surfaces show some repetitiveness. On some surfaces these repetitive features are clearly visible, either on the workpiece itself or the profile. The presence of certain repetitive features, however small, can indicate tool wear, machine vibration or machine deficiencies, so it is obviously important to identify them. If a profile were perfectly periodic such as a sine wave, the relationship of a given group of points will repeat exactly at a distance equal to the wavelength. The following procedure should be applied to determine the sampling length:

1. Estimate graphically the parameter RSm of the surface of unknown roughness.
2. Determine the corresponding sampling length using table 6.
3. Measure the RSm value using the sampling length setting determined in step 2.
4. If the RSm value obtained in step 3 relates to a smaller or greater cut-off wavelength value than in step 2, use the smaller or greater cut-off wavelength value. Otherwise, retain the cut-off wavelength (sampling length) used in step 2.
5. Obtain a representative measurement of the selected parameter(s) using the cut-off wavelength (sampling length) estimated in step 4.

RSm /mm	Roughness sampling length l_r /mm	Roughness evaluation length l_n /mm
$0.013 < RSm \leq 0.04$	0.08	0.4
$0.04 < RSm \leq 0.13$	0.25	1.25
$0.13 < RSm \leq 0.4$	0.8	4
$0.4 < RSm \leq 1.3$	2.5	12.5
$1.3 < RSm \leq 4$	8	40

Table 6 Estimates for choosing roughness sampling lengths for the measurement of periodic profiles, ISO 4288

Chapter summary

- Presents the 16 % rule.
- Presents the max-rule.
- How to select a cut-off wavelength.

Calibration

7

IN THIS CHAPTER

- Type A – Depth measurement artefact
- Type B – Tip condition measurement artefact
- Type C – Spacing measurement artefact
- Type D – Roughness measurement
- Type E – Profile co-ordinate measurement artefact
- Calibration Procedure
- Type F standards - software

Surface texture measuring instruments are calibrated using calibration artefacts (sometimes referred to as material measures). The calibration of a wide range of instruments operating in a variety of conditions demands more than one type of artefact. ISO 5436-1 identifies five main types of artefact, each of which may have a number of variants. Each of the calibration artefact types has a limited range of application according to its own characteristics and those of the instrument to be calibrated. These are summarised in Table 7. Type A artefacts are useful for checking the vertical magnification factor of an instrument but no information is given regarding the calibration of the instrument in the scanning axis. For this check, a Type C artefact should be used. It is always wise to check the overall calibration of an instrument, that is to say its overall ability to measure and calculate a surface texture parameter – for this calibration a Type D artefact is used. Lastly, one should always check that the stylus is performing to its specification – for this check a Type B artefact is used. It is, therefore, suggested that all users of surface texture measuring instruments have at least four artefacts available that have been previously calibrated using a higher-accuracy, traceable system. Type E artefacts are also required for checking the form measuring capabilities of an instrument. The calibration artefacts detailed above require calibration to a known standard. Interferometry or another stylus instrument that has been traceably calibrated can be used. There must be an unbroken and documented chain of calibration to the primary standard of length. This chain is a requirement of ISO 9000: 2005.

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

Table 7 Types and names of calibration artefacts

Type A – Depth measurement artefact

Type A1- Wide grooves with flat bottoms

Type A1 artefacts take the form of a wide calibrated groove 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 28). Each feature is wide enough to accommodate the shape or condition of the stylus

tip. A significant number of traces, a minimum of five, should be taken, distributed evenly over the measuring window.

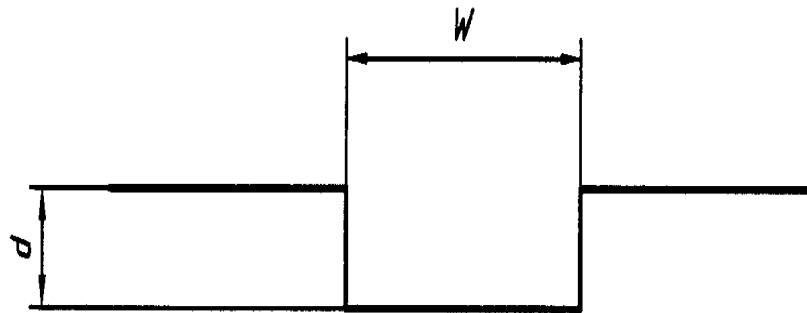


Figure 28 Type A1 calibration artefact, from ISO 5436-1

The following text from an older standard (BS 6393: 1987) describes how to measure Type A1 standards. “A continuous straight mean line equal in length to three times the width of the groove is drawn 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 (see figure 29). To avoid the influence of any rounding of the corners, the upper surface on each side of the groove is to be ignored for a length equal to one-third of the width of the groove. The surface at the bottom of the groove is assessed only over the central third of its width. The portions to be used for assessment purposes are therefore those at A, B, and C in figure 29. The depth d of the groove shall be assessed perpendicularly from the upper mean line to the mid-point of the lower mean line. A significant number, not less than five, of evenly distributed traces shall be taken.” Note that the where the standard suggests that the “...groove shall be assessed perpendicularly from the...”, this should say “...groove shall be assessed perpendicularly to the traverse axis from the...”.

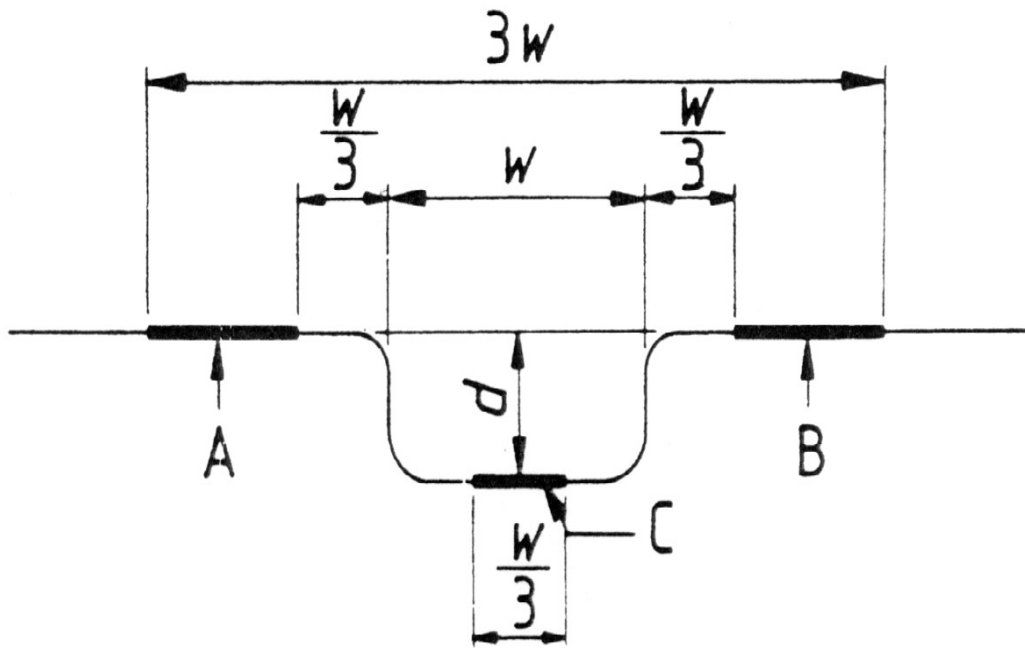


Figure 29 Procedure for the assessment of Type A1 artefacts

Type A2 – Wide grooves with rounded bottoms

This artefact is similar to Type A1 except that the grooves have rounded bottoms (see figure 30). The radius is sufficiently large to be insensitive to the shape or condition of the stylus tip. A significant number of traces, a minimum of five, should be taken, distributed evenly over the measuring window.

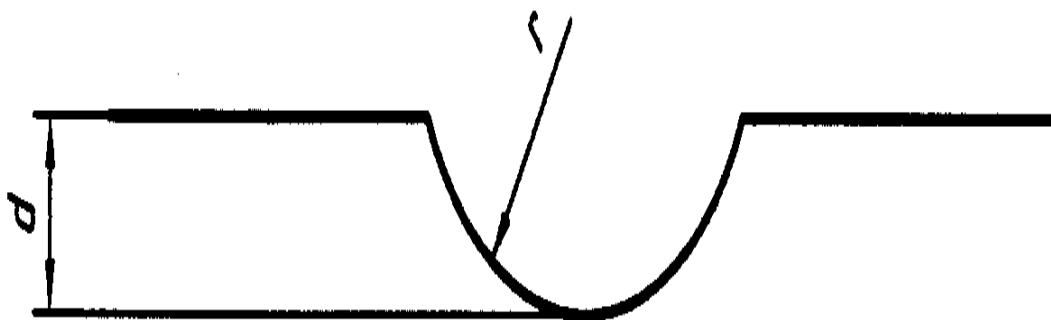


Figure 30 Type A2 calibration artefact, from ISO 5436-1

Type B – Tip condition measurement artefact

Type B1

These artefacts 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 the radiuses of which are sensitive to the stylus tip.

Type B2

These artefacts have two or more groove patterns on a common base. Comparing the Ra value on each groove patch indicates the stylus condition. A significant number of traces, a minimum of eighteen, should be taken, evenly distributed over the measuring window. A filter should be used having a λc cut-off according to the instruments certificate or according to ISO 4287.

The sensitive groove pattern is formed by isosceles triangular grooves that have sharp peaks and valleys (see figure 31) - Ra is dependent on the size of the stylus tip.

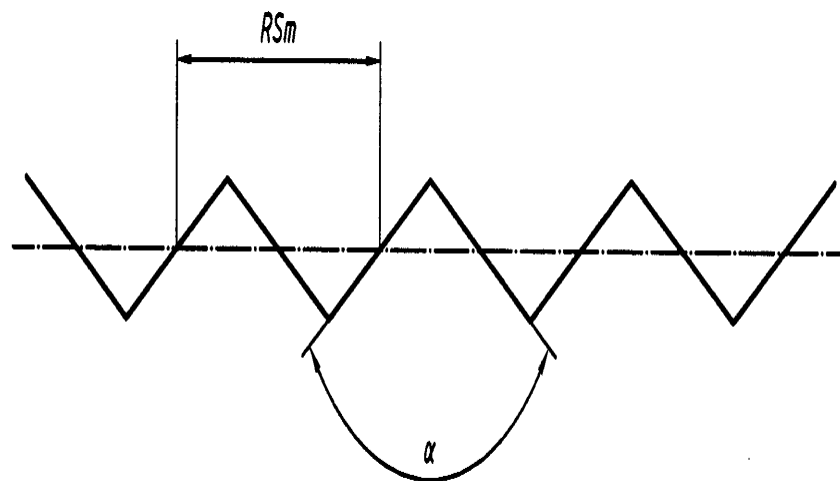


Figure 31 Type B2 calibration artefact, from ISO 5436-1

The insensitive groove pattern is formed by sinusoidal or arcuate grooves, which make Ra independent of the stylus tip (see figure 32).

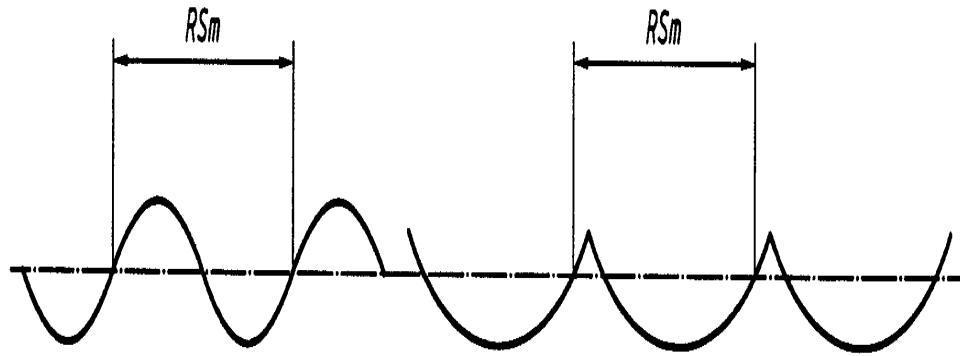


Figure 32 Type B2 calibration artefact, from ISO 5436-1

Type B3

This artefact has a fine protruding edge. The radius and apex angle must be smaller than the radius and apex angle of the stylus being assessed. The stylus condition can be assessed by traversing the specimen and recording the surface profile. This method can only be used with direct profiling instruments with low traversing speeds. Figure 33 illustrates the use of a Type B3 artefact that has been produced using a sharp razor blade. It should be noted that Type B3 artefacts made using commercially available razor blades are easily damaged and difficult to manufacture. It is preferable to use Type B1 or Type B2 artefacts.

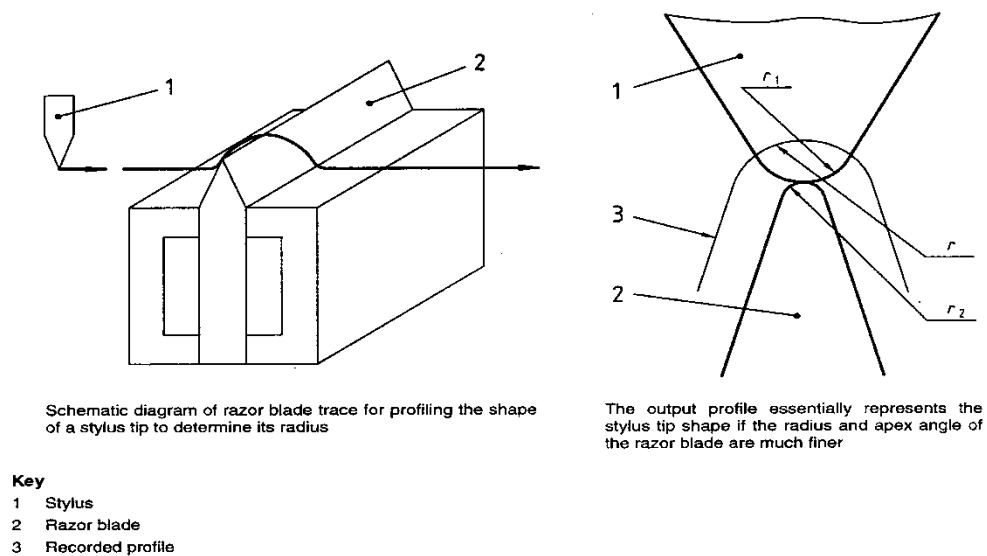


Figure 33 Type B3 calibration artefact, from ISO 5436-1

Type C – Spacing measurement artefact

These artefacts are used mainly for calibrating vertical profile components. However they can be used for the calibration of horizontal profile components providing the spacing of the grooves is held within limits acceptable for this purpose. They have repetitive grooves with various shapes.

Type C1

This artefact has grooves having a sine wave profile and is characterised by RS_m and Ra (see figure 34). The values chosen should ensure that the attenuation by the stylus or filter is negligible. A significant number of traces, a minimum of twelve should be taken, evenly distributed over the measuring window. The parameters should be calculated according to ISO 4287.

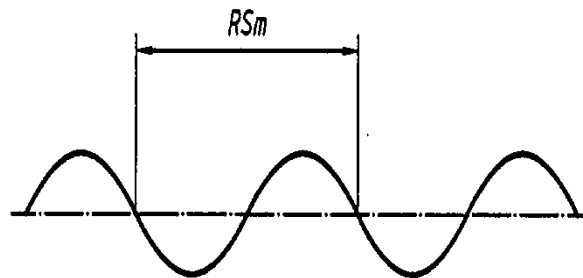


Figure 34 Type C1 calibration artefact, from ISO 5436-1

Type C2

This artefact has grooves having an isosceles triangular profile and is characterised by RS_m , Ra and the angle α (see figure 35). The values chosen should ensure that the attenuation by the stylus or filter is negligible. A significant number of traces, a minimum of twelve, should be taken evenly distributed over the measuring window. The parameters should be calculated according to ISO 4287.

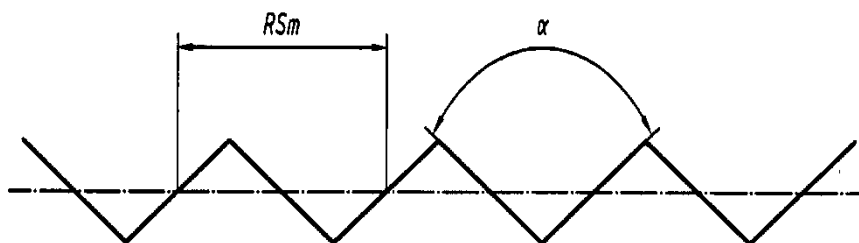


Figure 35 Type C2 calibration artefact, from ISO 5436-1

Type C3

This artefact simulates approximate sine wave grooves by means of a triangular profile with rounded or truncated peaks and valleys (see figure 36). A significant number of traces, a

minimum of twelve, should be taken evenly distributed over the measuring window. The parameters should be calculated according to ISO 4287.

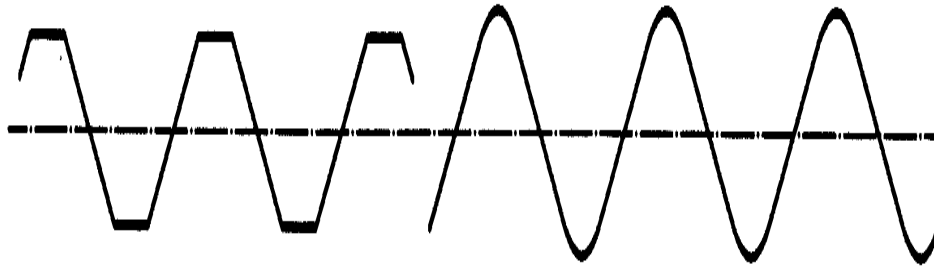


Figure 36 Type C3 calibration artefact, from ISO 5436-1

Type C4

This artefact has grooves with an arcuate profile and is characterised by PS_m and Pa (see figure 37). The values chosen should ensure that the attenuation by the stylus is negligible. A significant number of traces, a minimum of twelve, should be taken evenly distributed over the measuring window. The parameters should be calculated according to ISO 4287.

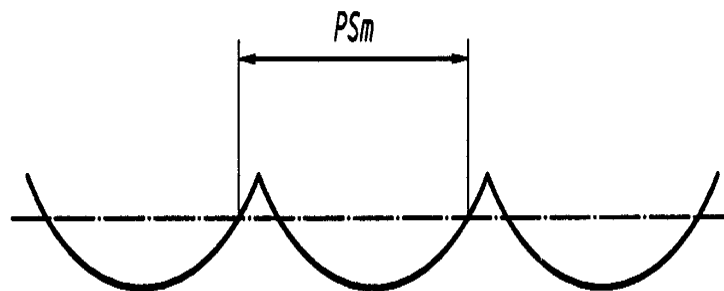


Figure 37 Type C4 calibration artefact, from ISO 5436-1

Type D – Roughness measurement artefact

These artefacts are commonly used for the overall calibration of instruments. To get the full benefit of the Type D artefact, it is normally necessary to average a statistically determined number of appropriately positioned tracings.

Type D1 – Unidirectional irregular profile

The artefact has an irregular profile in the direction of the traverse (similar to a ground profile) and that repeats in the longitudinal direction after some number (usually five) of the sampling lengths for which it is designed (see figure 38). The profile shape is constant normal to the measuring direction of the artefact. The artefact simulates workpieces containing a wide range of crest spacing and provides reassurance of a final overall check on calibration. The artefact is characterised by Ra and Rz .

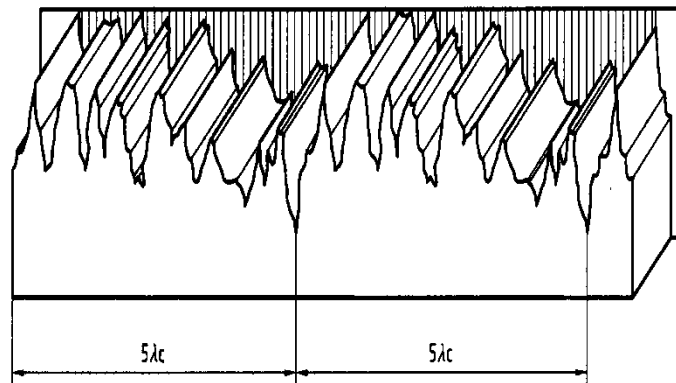


Figure 38 Type D1 calibration artefact, from ISO 5436-1

A significant number of traces, a minimum of twelve, should be taken evenly distributed over the measuring window. The parameters should be calculated according to ISO 4287. Note that these artefacts should be used only at the cut-off specified in their calibration certificate.

Type D2 – Circular irregular profile

This artefact is characterised by Ra and Rz and has irregular profiles repeated every $5\lambda_c$ in the radial direction (see figure 39). Normal to the measuring direction of the artefact (in the circumferential direction), the profile shape is constant. A significant number of traces, a minimum of twelve, should be taken evenly distributed over the measuring window. The parameters should be calculated according to ISO 4287. Note that these artefacts should be used only at the cut-off specified by their calibration certificate.

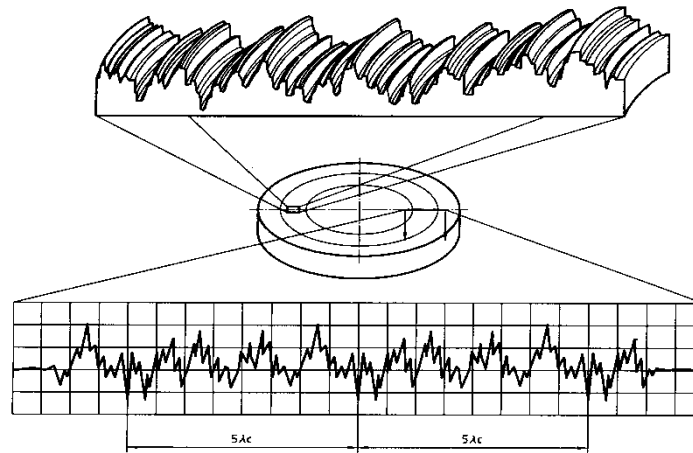


Figure 39 Type D2 calibration artefact, from ISO 5436-1

Type E – Profile co-ordinate measurement artefact

Type E1 – Spherical dome

This artefact is characterised by its radius and Pt . The radius of the sphere or hemisphere should be sufficient to allow the stylus tip to remain in contact with the surface and not foul on the stem of the stylus during the traverse that should be set symmetrically either side of the highest point of the intended trace.

Type E2 – Trapezoidal

This artefact is a precision prism characterised by the angles between the surfaces and Pt on each surface (see figure 40). The size and shape of the artefact should be such that the stylus tip remains in contact with the surface and does not foul 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 long enough to allow the artefact to be levelled in a stable manner.

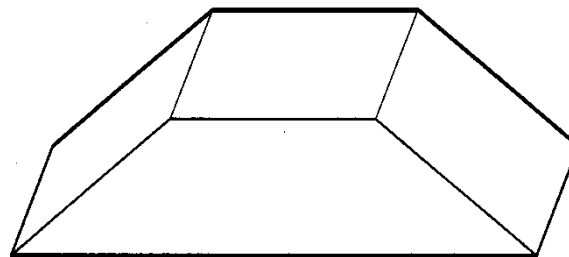


Figure 40 Type E2 calibration artefact, from ISO 5436-1

Calibration procedure

The instrument should be calibrated at the place of use and all ambient conditions that influence the instrument in service should be taken into consideration. Before calibration the operation of the stylus instrument should be checked against the manufacturer's operating instructions.

The key steps in calibration are as follows:

- Align the artefact to within 10 % of the measuring range.
- Select the measuring conditions:
 - sampling length
 - evaluation length
 - cut-off wavelength
- Carry out the specified measurements on each artefact distributed over the measurement surface.

Type F standards - software

Part 2 of ISO 5436 describes the use of reference software and reference data sets (softgauges) to aid in calibration of a surface texture measuring instrument. ISO 5436 part 2 defines Type F1 (reference data) and Type F2 (reference software) software measurement standards for testing the numerical correctness of software used in surface texture measurement. Reference software is used as a benchmark against which software in a measuring instrument can be compared. A data set is used as input to both the software under test and the reference software, and the results delivered by the software under test are compared with those provided by the reference software. Software measurement standards can be found at resource.npl.co.uk/softgauges/default.htm.

Chapter summary

- Discusses the different types of calibration artefacts.
- Discussed the calibration procedure.
- Discusses software measurement standards.

Uncertainties

8

IN THIS CHAPTER

- Uncertainty in the measurement of vertical displacement
- The influence quantities
- Further influence quantities
- Calculation of the total uncertainty in a vertical displacement
- Uncertainty in the displacement in the traverse direction
- Uncertainties in the surface texture parameters
- Measurement Uncertainty – A Worked example

The measurement of surface texture is a very complicated process that depends on a number of factors. For this reason it is not easy to calculate measurement uncertainties. For an introductory understanding of measurement uncertainties the reader is referred to NPL Measurement Good Practice Guide 11 (Issue 2). For a more thorough understanding of the subject the reader should refer to M3003, “The expression of uncertainty and confidence in measurement” (UKAS) and PD 6461 (1995) Vocabulary of metrology – Part 3. “Guide to the expression of uncertainty in measurement” (popularly known as the *GUM*). Note that this standard has been withdrawn as it is based on the 1993 edition of the Guide to the expression of uncertainty in measurement (GUM). ISO has recently republished the 1995 (corrected) edition of the GUM as ISO/IEC Guide 98-3:2008.

A rigorous uncertainty analysis is beyond the scope of this guide. However, the following is a simplified method that will always tend to overestimate the measurement uncertainty of a stylus instrument. The final uncertainty figures will be the uncertainty in the measurement of displacement in the x and z axes of the instrument. These values should always be quoted on a calibration certificate or with a measurement report. To calculate the uncertainties in some surface texture parameters, for example Ra , is a very complicated task and is usually only attempted by the laboratories close to the top of the traceability chain. However, the uncertainty in certain surface texture parameters, such as Rp or Rv can be calculated using the method described in the following sections. Guidelines for quoting the variation of a surface texture parameter over a surface are given.

Note that this uncertainty analysis relies on the fact that at least twelve repeat measurements are made on a surface (with the exception of the five measurements of the step height artefact).

Uncertainty in the measurement of vertical displacement

As discussed in section 7, 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 instrument. Such an artefact should ideally be supplied with a traceable calibration certificate on which there will be at least two numbers of interest (d_c and U_{d_c} described below).

Once the artefact has been measured and the instrument adjusted to read as close as possible to the value of the step height quoted on the certificate (if this is possible), the corrected measurement of a vertical height, Z , will be given by

$$Z = CZ_m \quad (8.1)$$

where Z_m is the measured height and C is the calibration factor given by

$$C = \frac{d_c}{d_m} \quad (8.2)$$

where d_m is the step height measured by the instrument and d_C is the step height quoted on the calibration certificate. Note that ISO 5436-1 advocates that a minimum of five measurements should be taken to determine d_m . Z_m will depend on a number of additive factors, but the most influential are represented in equation (8.3)

$$Z_m = Z_p + Z_{ref} + Z_n + Z_{pl} + Z_{tip}. \quad (8.3)$$

The factors that influence Z_m , and how they are determined, are now explained in detail in the section on influence quantities. Note that when measuring influence quantities, the instrument should already have been calibrated and adjusted as described above (that is to say, the value of C is close to unity).

The influence quantities

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, but is part of the measurement process.

Slideway profile, Z_{ref}

A measurement of height will be 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, that is to say the Pt value for the profile ($Z_{ref} = Pt$). This value will tend to make the measurement uncertainty larger than it is for a specific area of the datum, but will never allow the measurement uncertainty to be too small.

Instrument noise, Z_n

Every measurement made by the instrument will be subject to random measurement error that can be determined by taking a measurement without actually 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 of interest and the Pq value determined ($Z_n = Pq$).

Note that it is important to use an optical flat or Type E2 artefact that has flatness and surface texture less than the resolution of the instrument.

Plastic deformation error, Z_{pl}

Plastic deformation of the surface can occur and depends 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 from the literature a value

for Z_{pl} of 20 nm is probably pessimistic for a metal surface measured with a 2 μm radius stylus and a 0.75 mN stylus force. The value of Z_{pl} of 20 nm is, therefore, suggested unless calculations can be carried out to determine a more realistic value of Z_{pl} .

Effect of tip geometry, Z_{tip}

The uncertainty contribution due to tip geometry is only required when measuring surfaces with wavelength that are less than the radius of the stylus tip. The contribution of the tip geometry on a vertical height measurement can only be calculated for a number of very simple surfaces and is beyond the scope of this guide. Instead, the tip condition should always be checked using a Type B gauge (see chapter 7) and any measurements should be stated with the disclaimer “*The surface has been measured with a stylus of tip radius r μm , and any wavelength less than r μm will be distorted*”.

Further influence quantities

There will be a number of further factors that affect a measurement of surface texture, for example, expansion of the instrument due to temperature variations in the room, vibration of the instrument and the effect of any filters. Some of these quantities will be included in the factors described above. 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 must be added to any measurements that states the cut-off wavelengths used, for example, “*The surface has been measured using a cut-off wavelength, λ_c , of 0.8 mm*”. Of course, where other filters are used, such as λ_s and λ_f filters, the cut-off values must be quoted.

Calculation of the total uncertainty in a vertical displacement

The standard uncertainty, U , in measuring a height, Z , is calculated by inserting the influence quantities described above into equation (8.4). Details of how the equation was derived are not presented here, but the complications arise due to the need to calculate the sensitivities of the factors to the measurement and their statistical distributions.

$$U_Z^2 = Z_m^2 U_C^2 + C^2 U_{Z_m}^2 \quad (8.4)$$

where U_C is the standard uncertainty in the calibration constant and U_{Z_m} is the standard uncertainty in the actual measurement of a height, Z_m . U_C is given by

$$U_C^2 = \frac{U_{d_c}^2}{d_m^2} + \frac{d_c^2 U_{d_m}^2}{(d_m^2)^2} \quad (8.5)$$

U_{d_m} is the precision of the surface texture measuring instrument (the standard error of the mean of the repeated results to determine d_m) and U_{d_c} is the standard uncertainty quoted on the calibration certificate of the calibration artefact (note that this value may require a conversion factor, see the example in the section Worked Example later in this chapter). U_z is given by

$$U_z^2 = \frac{Z_{ref}^2}{12} + Z_n^2 + \frac{Z_{pl}^2}{3}. \quad (8.6)$$

Once all the values for the above terms have been calculated, the value for U_z can be found by simply taking the square root. This is known as the combined standard uncertainty. To calculate an expanded uncertainty at 95 % confidence, U_{TZ} , (required by UKAS), U_z should be multiplied by 2.

All this mathematics may seem a bit daunting at first, but really one only has to be able to multiply, divide and find squares and square roots. This is much easier to understand with the aid of an example (see section Measurement Uncertainty – A Worked Example). When calculating uncertainty, one should try to follow the example as much as possible.

Uncertainty in the displacement in the traverse direction

Once again, it is very complicated to calculate the uncertainty in a displacement measurement in the direction of scan or x axis. A full derivation is beyond the scope of this guide and should only be attempted by those laboratories that are close to the top of the traceability chain. To a close approximation, an uncertainty in the x axis need only be stated when quoting a spacing or hybrid surface texture parameter (see section on spacing parameters in chapter 3 and hybrid parameters also in chapter 3). A Type C artefact should be used to calibrate a displacement in the x axis with an RS_m as close as possible to that of the surface being measured (determined by the rules in chapter 6 Selecting a cut-off wavelength) and at least twelve measurements should be taken over different sections of the x axis. To a 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 beyond the scope of this guide. Therefore, if a hybrid parameter must be quoted or certified it should carry the disclaimer “*The uncertainty in this parameter has not been calculated, but the uncertainty in the x axis is $U_{TX} \mu m$ and the uncertainty in the z axis is $U_{TZ} \mu m$ at 95 % confidence*”.

Uncertainties in the surface texture parameters

Uncertainty in the amplitude parameters

The uncertainty in R_p , R_v , R_z , R_c and R_t is found by simply substituting the parameter value for Z in equation (8.4) and combining this in quadrature with the standard error of the mean of at least twelve measurements over different areas of the surface.

Uncertainty in the amplitude parameter (average of ordinates)

The uncertainty in R_a , R_q , R_{sk} and R_{ku} cannot be calculated as described earlier 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 quoted 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_{TZ} μm at 95 % confidence*”.

Uncertainty in the spacing and hybrid parameters

Uncertainty in the spacing parameters has been dealt with in the section on uncertainty in the displacement in the traverse direction 8.5.

Measurement uncertainty – a worked example

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

We shall first consider the uncertainty in the z displacement. To determine U from equation (8.4) we first need to calculate equations (8.5) and (8.6). The terms in equation (8.5) are the following:

- d_m the measured value of the depth of the Type A1 artefact using ACMESURF, in this case 330 nm,
- d_c the calibrated value of the depth of the Type A1 artefact quoted on the certificate, in this case 301 nm,
- U_{d_m} the standard error of the mean of five repeat measurements of d_m using ACMESURF, in this case 30 nm,
- U_{d_c} the uncertainty in the calibrated depth of the Type A1 artefact quoted on the calibration certificate, in this case 12 nm, but this is quoted with a coverage factor of 2 so the value of U_{d_c} is 6 nm.

Inserting these values into equation (8.5) gives:

$$U_C^2 = \frac{6^2}{330^2} + \frac{301^2 \times 30^2}{(330 \times 330)^2} = 0.0072.$$

Therefore, $U_C = \sqrt{0.0072} = 0.0849$ nm. The terms in equation (8.6) are:

- Z_{ref} the error in the slideway profile, in the case an optical flat was measured to have a Pt value of 27 nm,
- Z_n the instrument noise, in this case an optical flat was measured to have a Pq value of 14 nm,
- Z_{pl} the error due to plastic deformation, in this case taken as 20 nm.

Inserting these values into equation (8.6) gives:

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

Therefore, $U_Z = \sqrt{390.08} = 19.751$ nm.

The terms in equation (8.4) are now:

- U_C = from equation (8.5), in this case 0.0849 nm,
- C = the ratio of d_C to d_m , in this case $301/330 = 0.9124$,
- U_{Z_m} = from equation (8.6), in this case 19.751 nm,
- Z_m = the z displacement that is measured.

Inserting these values into equation (8.4) gives:

$$U_Z^2 = Z_m^2 \times 0.0849^2 + 0.9124^2 \times 19.751^2 = 324.750 + 0.0072 \times Z_m^2.$$

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

$$U_{TZ} = 2 \times \sqrt{324.750 + 0.0072 \times Z_m^2} \text{ nm.}$$

Table 8 shows the change in U_{TZ} with measured height, Z_m . It can be seen that the term in the equation for U_{TZ} that depends on Z_m only begins to take effect around 100 nm.

Z_m / nm	U_{TZ} / nm
1	37
10	37
100	40
1000	174

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

To calculate the uncertainty in the x direction, a Type C3 sinusoidal artefact with a period of $0.25 \mu\text{m}$ was measured by ACMESURF in twenty locations and the RSm value calculated for each measured profile. A mean value of $0.256 \mu\text{m}$ with a standard deviation of 18 nm was calculated from the RSm values. As discussed in section 8.5, the value of the standard error of the mean is the value quoted as the standard uncertainty, so the combined uncertainty in a measurement of displacement in the x axis is U_{TX} is 8 nm at 95% confidence ($2 \times 18/\sqrt{20}$).

Twelve measurements are then made using ACMESURF of Rp , Ra and RSm . The mean value of Rp was calculated to be 1213 nm with a standard error of the mean of 40 nm , the mean value of Ra was 45 nm with a standard deviation of 7 nm and the mean value of RSm was 108 nm with a standard deviation of 31 nm . The measurement results should be quoted as in table 9. Note 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. By substituting $Z = 1213$ into $\sqrt{324.750 + 0.0072 \times Z^2}$ a value of $U_Z = 104 \text{ nm}$ is obtained. The combined uncertainty in Rp is found by adding 40 nm in quadrature with 104 nm , that is to say. $\sqrt{40^2 + 104^2} = 112 \text{ nm}$ and multiplying by 2 to give the expanded uncertainty at 95% confidence.

Parameter	Parameter value/nm	Standard deviation/nm	Expanded Uncertainty/nm
Rp	1213	139	224
Ra	45	7	4
RSm	108	31	8

Table 9 Quoted uncertainties for measurements made with ACMESURF

Along with the table, the following disclaimers should be stated:

“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 at 95% confidence”.

“The uncertainty in RSm has not been calculated, but the uncertainty in the x axis is 8 nm at 95% confidence”.

Chapter summary

- Discusses the various influence quantities.
- Shows how to calculate of the total uncertainty in a vertical displacement.
- Shows how to calculate the uncertainty in the displacement in the traverse direction.
- Shows how to calculate uncertainties in the surface texture parameters.
- Gives a worked example of an uncertainty calculation.

Health and safety

9

IN THIS CHAPTER

- Mechanical hazards
- Chemical hazards

Surface texture measuring instrument and artefacts themselves are intrinsically safe. Hazards are, therefore, likely to arise mainly from their mis-use. Some specific things to look for when carrying out a risk assessment are listed below.

Mechanical hazards

Some measurement artefacts may be relatively heavy (for example, an engine block). The appropriate lifting techniques and equipment should always be used and safety shoes worn. Operators should wear laboratory coats or overalls for safety reasons and to prevent fibres shed from clothing from falling on items being measured.

Chemical hazards

Chemicals may need to be used for cleaning purposes. Make sure the manufacturer's safety guidance is followed and the relevant personal protective equipment worn. Substances may be covered by the COSHH regulations.

- Take care when using cleaning solvents and oils and always wear the appropriate protective equipment.

Appendices

10

IN THIS CHAPTER

- Appendix A Parameters previously in general use.
- Appendix B Appendix B Specifying surface texture ISO 1302.
- Appendix C Links to other useful sources of information

Appendix A Parameters previously in general use

The following descriptions may appear on older machines and in older literature and are, therefore, included for completeness. However, where possible the up-to-date specification standards should be used.

Roughness profile: R

The roughness profile is an assessed profile, which is obtained from the primary profile by filtering out longer waves (waviness component) as specified by the cut-off length λ_c . Note that the λ_c described in this Appendix is not the same as that in the modern standards.

Filtered waviness profile: WC

The filtered waviness profile is an assessed profile which is obtained from the primary profile by filtering out shorter wavelengths (roughness component) as specified by cut-off length λ_f . Note that the λ_f described in this Appendix is not the same as that in the modern standards.

Filtered centre line waviness profile: WCA

The filtered centre line waviness profile is an assessed profile which is obtained from the primary profile by filtering longer waves (waviness components), as specified by λ_c and shorter waves (roughness components), as specified by λ_f while passing mid-range waves.

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 λ_c and λ_f , respectively. The sampling length of WCA corresponds to λ_f .

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 will be collected. A standard roughness evaluation length comprises five sample lengths. The sample length is always equal to the filter cut-off length. In general evaluation of 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 (ISO/JIS), Pc , Sm , HSC and S). However, depending on the parameters, the evaluation values may use the maximum value of the entire length (for example, Ry (DIN), Rp , Rv and Rt).

Traverse length: lt

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

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.

Third point height: R_{3Z}

This parameter provides a simpler method of obtaining the kind of average value that R_z provides but entails two instead of ten points. It is the distance between the third highest peak and the third lowest valley. The two parameters will not necessarily give the same result. The method should be regarded as a means of estimating the true mean given by R_z . The parameter is used in Japan and Germany within the automotive industry.

Maximum height of the profile: R_y (ISO/JIS)

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. R_y (ISO/JIS) is the mean value of the maximum peak-to-valley heights in the evaluation length.

Maximum height of the profile: R_y (DIN)

The maximum height of the profile is the distance between the maximum peak height and the minimum valley depth from the mean line in sampling length. R_y (DIN) is the maximum value of the maximum peak-to-valley heights in the evaluation length.

Total peak-to-valley height: R_t

The total peak to valley height is the sum of the maximum profile peak height R_{pmax} and the maximum profile valley depth R_{vmax} , the vertical height between the highest and lowest points on the profile within the evaluation length. R_t is used to specify maximum roughness height rather than the mean height that R_a gives. This parameter is used when tactile assessment of the surface is required for handling purposes.

Peak to valley heights

- Maximum peak-to-valley height within the sampling length L : R_{max} .
- The mean value of the R_{max} of five consecutive sampling lengths: R_{tm} .
- Height of the highest point of the profile above the centre line within the sampling length L : R_p .
- The mean value of the R_p of five consecutive sampling lengths: R_{pm} .

Peak count: P_c

The peak count is the number of peak-valley pairs (cycles) per unit length along the mean line of the profile within the sampling length. Two lines (count levels) that are parallel to the mean line are drawn at equal distances above and below the mean line. 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.

Mean spacing of profile irregularities: S_m

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

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 (count level) that is parallel to the mean line is drawn above the mean line. Each peak that projects above the specified count level and has a local peak is known as a high spot count peak. Note: 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.

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.

Amplitude distribution curve: ADC

Assume that 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.

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 which are drawn at equal intervals within Rt : parameter δc (Plateau ratio) determines the distance between the two slice levels which 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

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. Note that in the older standards the y axis is the same as the z axis in the new standards.

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 in contact with one another wear takes place, the bearing ratio simulates the effect of this wear. There are limitations to its effectiveness in predicting wear due to the measurement being taken over a length and not an area. It is determined over a short sample length and ignores waviness and form and in practice two contacting surfaces are involved and each will have surfaces that play a part in causing wear.

Core roughness depth: R_k

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

These parameters are obtained from the BAC graph:

- Reduced peak height: R_{pk}
- Reduced valley height: R_{vk}
- Reduced peak area: A_1
- Reduced valley area: A_2
- Material ratio 1: m_{r1}
- Material ratio 2: m_{r2}

Maximum height of the profile: R_y (ISO/JIS)

The maximum height of the profile is the distance between the maximum peak height and the maximum valley depth from the mean line in each sampling length. R_y (ISO/JIS) is the mean value of the maximum peak-to-valley heights in the evaluation length.

Average wavelength: λ_a or λ_q

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

Appendix B Specifying surface texture ISO 1302

The user should be aware of the rules for the indication of surface texture in technical product documentation such as drawings, specifications, contracts and reports. This is communicated by means of graphical symbols and textual indications.

The basic graphical symbol illustrated in figure 41 should not be used without the inclusion of complementary information. It may only be used in isolation when its meaning is "the surface under consideration" or explained by a note.

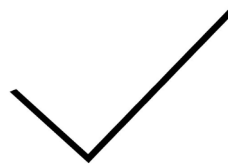


Figure 41 Basic graphical symbol for surface texture, from ISO 1302

B.1 Expanded graphical symbols

B.1.1 Removal of material required to obtain the indicated surface texture value

If removal of material is necessary in order to obtain the specified surface, a bar is inserted to the basic graphical symbol; this is illustrated in figure 42. However, the expanded graphical symbol should not be used without complementary information. If used in isolation its meaning will indicate "a surface to be machined".

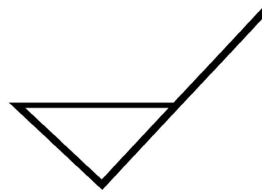


Figure 42 Graphical symbol for surface texture where material removal is required,

B.1.2 Removal of material not permitted

If removal of material is not permitted for obtaining the specified surface, a circle is added to the basic graphical symbol (see figure 43). This symbol may also be used on a drawing to relate to a manufacturing process to indicate a surface is to be left in the state resulting from a preceding manufacturing process.

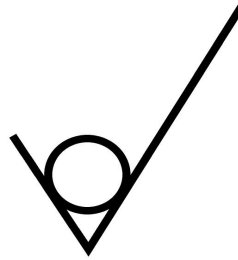


Figure 43 Graphical symbol for surface texture where material removal is not permitted, from ISO 1302

B.2 The complete graphical symbol

When it is necessary to add complementary information, a horizontal line is added to any of the graphical symbols illustrated in figures 41 to 43. The complete symbols are indicated in figure 44.

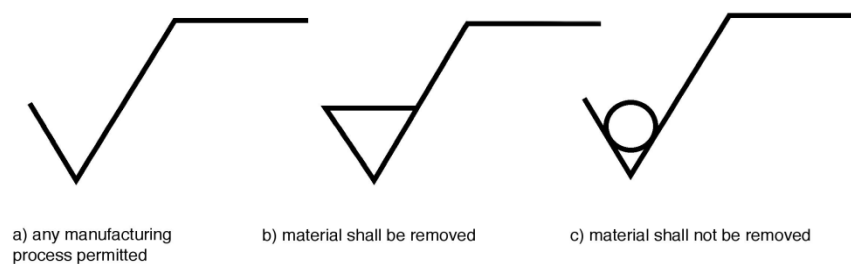


Figure 44 Graphical symbol for surface texture where complimentary information is required, from ISO 1302

B.3 Graphical symbol for “all surfaces around workpiece outline”

A further addition to the graphical symbol can be made if the same surface texture is required on all surfaces around a workpiece outline. This is represented by the addition of a circle as shown in figure 45.

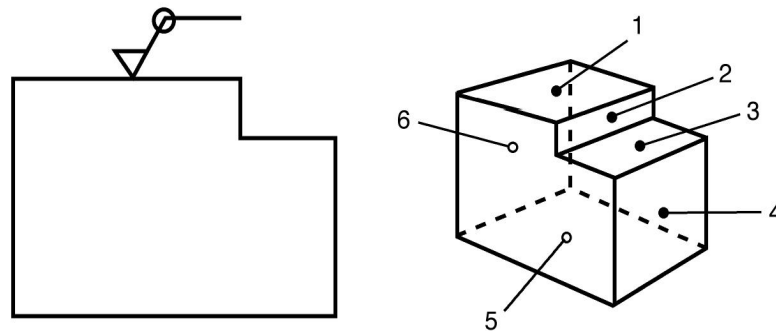


Figure 45 Graphical symbol for surface texture where the same texture is required on different surfaces, from ISO 1302

The surfaces indicated represent the six surfaces shown in the 3D representation; these do not include the front and rear surfaces of the workpiece.

B.4 Complete graphical symbol for surface texture

In order to ensure that the surface texture requirement is expressed without ambiguity, further information is added to the graphical symbol. This complementary information can be used to indicate the following:

1. Surface texture parameter.
2. Numerical value of the parameter.
3. Transmission band or sampling length.
4. Manufacturing process.
5. Surface lay and orientation.
6. Possible machining allowances.

It may be necessary to use one or a number of the above in order to indicate the surface required.

B.5 Position of complementary surface texture requirements

There are a number of mandatory positions for the various surface texture requirements and these are placed on the graphical symbol as detailed below in figure 46.

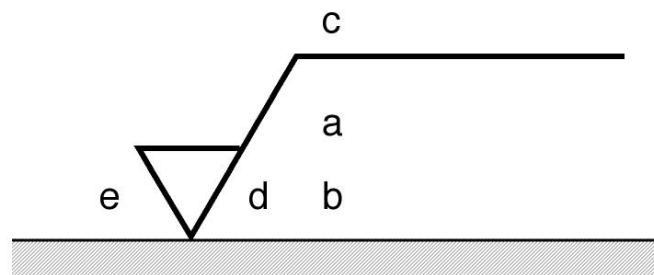


Figure 46 Graphical symbol for surface textures where there is more than one requirement, from ISO 1302

Position a - one single surface texture requirement

Position b - second surface texture requirement

Position c - manufacturing method

Position d - surface lay and orientation

Position e - machining allowance

B.6 Surface lay and orientation

The symbols indicating surface lay and its orientation are indicated in Table 10.

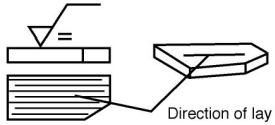
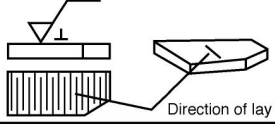
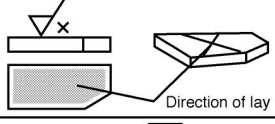
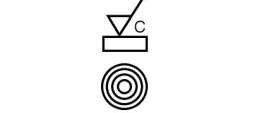
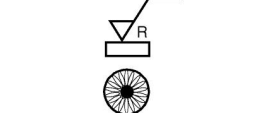
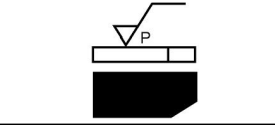
Graphic symbol	Interpretation and example	
=	Parallel to the plane of projection of the view in which the symbol is used	
⊥	Perpendicular to the plane of projection of the view in which the symbol is used	
×	Crossed in two oblique directions relative to the plane of projection of the view in which the symbol is used	
M	Multi-directional	
C	Approximately circular relative to the centre of the surface to which the symbol applies	
R	Approximately radial relative to the centre of the surface to which the symbol applies	
P	Lay is particulate, non-directional, or protuberant	
NOTE - If it is necessary to specify a surface pattern which is not clearly defined by these symbols, this shall be achieved by the addition of a suitable note to the drawing		

Table 10 Graphical symbols for surface texture lay, from ISO 1302

B.7 Minimum indications in order to ensure unambiguous control of surface functions

A surface texture requirement is built up of several different control elements, which can be part of the indication expressed on the drawing or the surface texture information given in other documents. The elements are the shown in Figure 47.

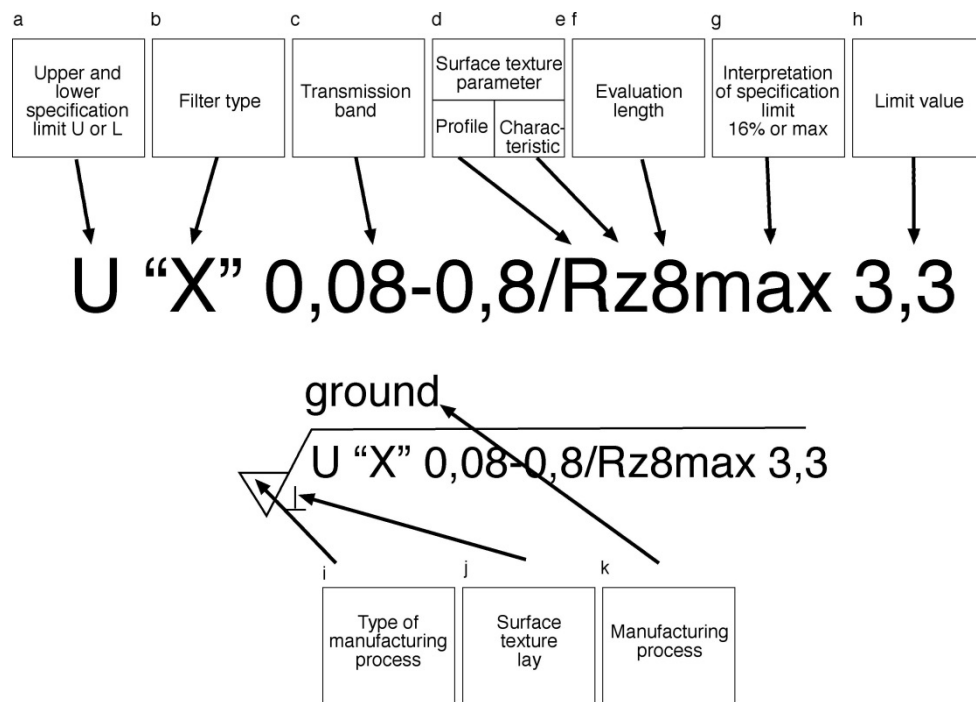
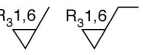
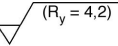
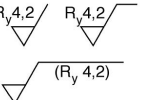
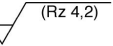
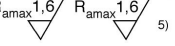
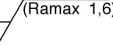
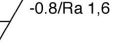
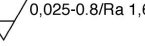
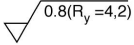
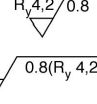
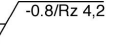
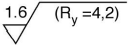
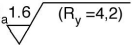
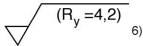
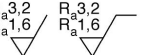


Figure 47 Minimum indications to endure control of surface functions, from ISO 1302

B.8 Evolution of drawing indication of surface texture

The user should take care when inspecting surface texture, for example when a manufacturing engineer, a machinist and an inspector consult the specification of a component, they do not necessarily know what parameter to follow. The engineer may write a specification based on an old or a new standard. The machinist may be working to an old or new drawing or technical specification document. The specification may have been produced in a design/development department operating under different national or international standards.

Table 11 indicates the evolution of drawing indications of surface texture requirements from former editions of ISO 1302.

Editions of ISO 1302			Main issue to be illustrated by example
1971 (Recommendation) ¹⁾ 1974 (1. edition) ¹⁾ 1978 (2. edition) ¹⁾	1992 (3. edition) ²⁾	2001 (4. edition) ³⁾	
a 			Ra only - "16%-rule"
b 			Parameter other than only Ra only - "16%-rule"
c 			"Max-rule"
d 			Ra plus sampling length
e 			Transmission band
f 			Parameter other than only Ra plus sampling length
g 			Ra plus parameter other than Ra
h 			Number of sampling lengths in the evaluation length - other than 5
j 			Lower limit
k 			Upper and lower limit

1) No defaults nor any other details defined, especially

- No default evaluation length
- No default sampling length
- No 16% or max rule

2) Defaults and details defined only for parameters R_a , R_t and R_z (ten-point height) in ISO4287/1: 1984 and ISO4288: 1985. Furthermore, there was a problem in ISO1302: 1992 where the text of the main body of the standard called for an indication of these conditions of the parameter symbol to be in subscript. In all illustrations the second letter is a normal lowercase! All other surface texture standards at that time used subscript.

3) Defaults and details defined for the majority of parameters R_y is renamed R_z . The old R_z is not standardized anymore.

4) Not covered.

5) There was a problem in ISO1302:1992 where clause D.3 included a misinterpretation of $Ra1,6$ max. The parameter designation was not in accordance with the parameter designation definition in clause 4 of ISO4288:1985 which called for R_{amax} 1,6.

6) See 5.9 of ISO4287/1:1984.

Table 11 Evolution of drawing indications, from ISO 1302

The information included above is for general information only. The user should ensure awareness of ISO 1302. This standard explains in greater detail the indication of surface texture in drawings and specification documents, and gives a number of examples in order to aid clarity.

Appendix C Links to other useful sources of information

C.1 National and International Organisations

C.1.1 National Physical Laboratory

"When you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot express it in numbers your knowledge is of a meagre and unsatisfactory kind."

Lord Kelvin, British Scientist (1824 – 1907)



The National Physical Laboratory (NPL) is the UK's national measurement institute and is a world-leading centre of excellence in developing and applying the most accurate measurement standards, science and technology available. For more than a century NPL has developed and maintained the nation's primary measurement standards. These standards underpin an infrastructure of traceability throughout the UK and the world that ensures accuracy and consistency of measurement.

NPL ensures that cutting edge measurement science and technology have a positive impact in the real world. NPL delivers world-leading measurement solutions that are critical to commercial research and development, and support business success across the UK and the globe.

Good measurement improves productivity and quality; it underpins consumer confidence and trade and is vital to innovation. NPL undertake research and shares its expertise with government, business and society to help enhance economic performance and the quality of life.

NPL's measurements help to save lives, protect the environment, enable citizens to feel safe and secure, as well as supporting international trade and companies to innovation. Support in areas such as the development of advanced medical treatments and environmental monitoring helps secure a better quality of life for all.

NPL employs over 500 scientists, based in south west London, in a laboratory, which is amongst the world's most extensive and sophisticated measurement science buildings.

The National Physical Laboratory is operated on behalf of the National Measurement Office by NPL Management Limited, a wholly owned subsidiary of Serco Group plc. For further information: Switchboard 020 8977 3222 | www.npl.co.uk/contact

C.1.2 National Institute of Standards and Technology (NIST)

NIST is the equivalent of NPL in the United States of America. Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Department of Commerce. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve quality of life.

The NIST web site at www.nist.gov often contains documents relevant to this guide in Adobe portable document format (PDF).

C.1.3 EURAMET

The European Association of National Metrology Institutes (EURAMET) is a Regional Metrology Organisation (RMO) of Europe. It coordinates the cooperation of National Metrology Institutes (NMI) of Europe in fields such as research in metrology, traceability of measurements to the SI units, international recognition of national measurement standards and related Calibration and Measurement Capabilities (CMC) of its members. Through knowledge transfer and cooperation among its members EURAMET facilitates the development of the national metrology infrastructures.

EURAMET serves the promotion of science and research and European co-operation in the field of metrology.

This is realized by the following measures in particular:

- development and support of European-wide research co-operation in the field of metrology and measurement standards;
- development, regular updating and implementation of a European Metrology Research Programme (EMRP) and its successor the European metrology Programme for Innovation and Research (EMPIR) ;
- support of members and associates when applying for research funds for the purpose of European cooperative projects;
- co-ordination of joint use of special facilities;
- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards;

- technical co-operation with metrology institutes beyond EURAMET and with other regional and international metrology organisations;
- performing the tasks of a Regional Metrology Organisation (RMO) with the objective of worldwide mutual recognition of national measurement standards and of calibration and measurement certificates;
- promotion and co-ordination of scientific knowledge transfer and experience in the field of metrology;
- representing metrology at the European level and promoting best practice to policy and political decision makers with regard to the metrological infrastructure and European co-operation;
- co-operation with European and international organisations responsible for quality infrastructure, in particular by participation in the preparation of harmonized technical documents.

For more information visit the EURAMET web site at: www.euramet.org

C.1.4 Institute for Geometrical Product Specification

More information about GPS can be found at the Institute for Geometrical Product Specification website www.ifgps.com. Click on resources for more information on GPS.

C.2 Networks

C.2.1 Measurement Network – Engineering and Optical

This special interest group reflects a range of interests from a number of sectors, including advanced manufacturing and engineering, transport and energy. It aims to ensure that the needs of members with an interest in dimensional, mass, temperature and optical measurement are reflected in the range of events held under the Measurement Network. These events provide a forum which enable members to exchange views and information.

For further information visit the website at: www.npl.co.uk/measurement-network/engineering-optical/

C.2.2 Software Support for Metrology Programme (SSfM)

SSfM is an programme that underpins the NMS, focussing on the use of mathematics and computing in metrology. It aims to achieve a balance between research and development, whilst also extending the range of techniques and applications available to meet the continually changing needs of metrology. The overall aim of the SSfM Programme is to tackle a wide range of generic issues, some of which are problems in metrology that require the application of established software engineering practices, whilst others require advances in mathematics, software engineering or theoretical physics. The programme, thus, includes work in metrology, mathematics, software and theoretical physics, with strong links between the various disciplines.

The SSfM Club is aimed at users and suppliers of metrology software, giving them a say in the direction of the Programme. It is the focal point for the distribution of general information arising from the Programme.

Further details can be found at website: <http://www.npl.co.uk/category/384>

C.3 National and International Standards

C.3.1 British Standards Institution (BSI)

BSI started in 1901 as a committee of engineers determined to standardise the number and type of steel sections in order to make British manufacturers more efficient and competitive. The BSI Group is now the oldest and arguably the most prestigious national standards body in the world and is among the world's leading commodity and product testing organisations. Website www.bsigroup.com.

C.3.2 International Organisation for Standardization (ISO)

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from some 140 countries.

The mission of ISO is to promote the development of standardisation and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological and economic activity.

ISO's work results in international agreements that are published as International Standards.

Further information on ISO can be found at: www.iso.ch

C.4 Traceability

Traceability in measurement is the concept of establishing a valid calibration of a measuring instrument or measurement standard, by a step-by-step comparison with better standards up to an accepted or specified standard. In general, the concept of traceability implies eventual reference to an appropriate national or international standard.

The National Physical Laboratory is the United Kingdom's national standards laboratory. It operates at the heart of the National Measurement System (NMS) which is the infrastructure designed to ensure accuracy and consistency in every physical measurement made in the UK. Chains of traceability link UK companies' measurements directly to national standards held at NPL.

For the majority of industrial applications, companies can establish a link to national measurement standards through the calibration and testing services offered by United Kingdom Accreditation Service (UKAS) accredited laboratories, which are in turn traceable to NPL. However, for challenging or novel measurements to the highest standards of accuracy,

which are not catered for by UKAS-accredited laboratories, NPL can often provide a traceable measurement solution directly to industry.

The United Kingdom Accreditation Service is the sole national accreditation body recognised by government to assess, against internationally agreed standards, organisations that provide certification, testing, inspection and calibration services.

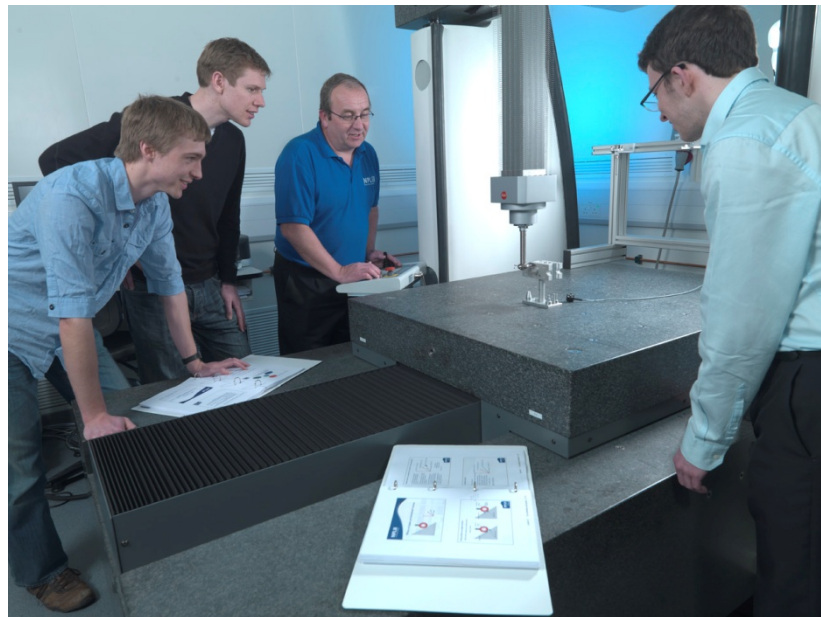
Accreditation by UKAS demonstrates the competence, impartiality and performance capability of these evaluators.

UKAS is a non-profit-distributing private company, limited by guarantee. UKAS is independent of Government but is appointed as the national accreditation body by the Accreditation Regulations 2009 (SI No 3155/2009) and operates under a Memorandum of Understanding with the Government through the Secretary of State for Business, Innovation and Skills.

UKAS accreditation demonstrates the integrity and competence of organisations providing calibration, testing, inspection and certification services.

Further information on UKAS can be found at: www.ukas.com.

C.5 Training courses



C.5.1 Dimensional measurement Training: Level 1 – Measurement User

A three day training course introducing measurement knowledge focusing upon dimensional techniques.

Aims & Objectives

To provide:

- the underpinning knowledge and expertise for anyone who uses measurement tools or requires an appreciation of the importance of measurement,
- the principle knowledge and practical training for people who are required to use dimensional measurement techniques to complete their daily tasks; and
- the tools to instil and encourage questioning culture.

Enabling:

- An understanding of the fundamentals of standards, traceability, calibration, uncertainty, repeatability, drawing symbols and geometrical tolerances, the importance of the relationship between tolerances and measuring equipment and be able to question the measurement.

Level 1 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training levels – 2 & 3.

Course Content

Day 1 - Geometric Product Specification (GPS) A

Including what is GPS, drawing practice and geometrical tolerances.

Day 2 - Measurement Principles and Methods A

Including successful measurements, standards, traceability, calibration, uncertainty, units, relationship between tolerances and measuring equipment using micrometers and callipers, repeatability and reproducibility of measurements.

Day 3 - Measurement Principles and Methods B

Including the relationship between tolerances and measuring equipment by the use of height gauges, dial test indicators, dial gauges, plug gauges, gap gauges and temperature effects.

NB: Fundamental Measurement Calculation is incorporated into all 3 days including powers, scientific notation and triangles. This is achieved by understanding the relationship of these calculations when applied to tolerance zones and practical measuring tasks.

A workbook of evidence must be completed successfully during the training course and, where required, post assessment tasks can be set for each individual to be completed in the workplace.

C.5.2 Dimensional Measurement Training: Level 2 - Measurement Applier

A four day training course for those who have a good basic understanding of measurement principles gained through the Level 1 training course.

Aims & Objectives

To provide:

- the underpinning knowledge and expertise for anyone who uses measurement tools or requires an appreciation of the importance of measurement,
- the principle knowledge and practical training for people who are required to use co-ordinate measurement techniques to complete their daily tasks; and
- the tools to instil and encourage questioning and planning culture

Enabling:

- a visible return on investment for a manufacturing organisation in the form of various production cost savings and an upskilled workforce,
- a reduction in re-work time and waste on the production line - faults and problems will be detected earlier in the production process; and
- An in-depth appreciation of *why* measurement is carried out and not simply *how*

Level 2 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training levels – 3 & 4.

A workbook of evidence must be completed successfully during the training course and, where required, post assessment tasks can be set for each individual to be completed in the workplace.

Course Content

Geometric Product Specification (GPS) B

Content covered:

GPS standards; Envelope tolerance; Size Principles; ISO Limits and Fits
Projected tolerance; Free state condition; Virtual condition; Maximum Material
Condition principles; Geometrical tolerancing measurements using first
principle measuring equipment; Surface texture principles.

Measurement Principles and Methods C

Content covered:

Calibration; Uncertainties; Traceability; Procedures; First Principle
Measurement; Angle plate; Gauge blocks; Surface plate; Height micrometer;
Sine bar or sine table.

Process Control A

Content covered:

Statistical Process Control theory; Variation – common, special causes;
Prevention versus detection; Collecting and calculating data when using
measuring tools; Callipers; micrometers; Basic charts – Tally chart/Frequency
Table, Histogram, Control Chart; Reacting to variation; Benefits of process
control; Standard deviation; Capability indices; Fundamentals of Gauge R&R.

Measurement Principles and Methods D

Content covered:

Taper calculations; Angles; Diameters; Searching for triangles; Chords; Radians; Manipulation of formula.

Co-ordinate Principles A

Content covered:

Application of equipment: First principles; Co-ordinate Measuring Machine; Optical and vision machines; Articulating arm; Laser tracker; Projector; Microscopes; Height gauge with processor; Contour measurement equipment.

Machine performance: Calibration standards; Self-verification/artefacts; Measurement volume.

Alignment Techniques: 321/point system alignment; Flat face alignment; Axes alignment; Car line/engine centre line.

Machine appreciation: Ownership; Care; Respect; Cost; Contribution to the business.

Work Holding: Fixturing; Rotary table; Clamping; How to hold the part; Influence of component weight, size, shape; Free state; Restrained state.

Co-ordinate geometry: Points; Plane; Line; Circle; Cylinder; Cone; Sphere; Ellipse.

Sensor Types: Probing Strategies; Relevant standards; Environment.

Measurement Strategies: Number of points; Partial arc; Contact/non-contact.

Co-ordinate methods A (OEM Training - equipment specific)

Content covered:

First principles; Co-ordinate Measuring Machine; Optical and vision machines; Articulating arm; Laser tracker; Projector; Microscopes; Height gauge with processor; Contour measurement equipment.

C.5.3 Mitutoyo training courses

The Mitutoyo Institute of Metrology offers qualifications and training in over thirty metrology related subjects. Mitutoyo training programmes are vocation based and are accredited with the Open College Network (<http://www.nocn.ac.uk>) for a qualification in Dimensional Metrology. These credits in turn, contribute towards the evidence route of the Technical Services Engineering NVQ recently accredited by EMTA (Engineering and Maritime Training Authority). These courses are recognised nationally and are available in various areas of metrology.

See the Mitutoyo training pages <http://www.mitutoyo.co.uk/service-and-support/training/> for more information.

C.5.4 NPL E-Learning

Access over a century of **measurement knowledge** and **state-of-the-art techniques**, quality assured from the UK's National Measurement Institute. NPL's new e-Learning programme delivers measurement training, globally accessible across PCs and mobile devices, helping to provide confidence, value and performance from your measurement systems.

Engage with cost-effective on-demand content, globally accessible through an easy-to-use professional solution, compatible across devices.

NPL e-Learning offers:

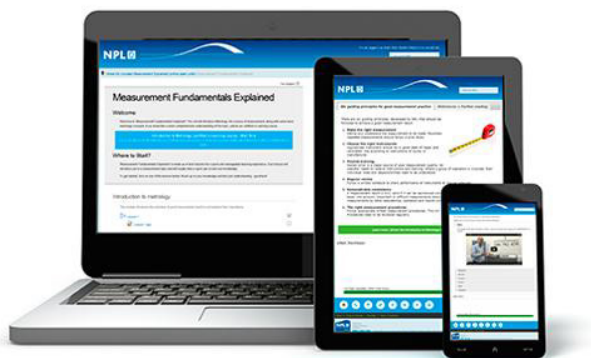
- metrology training courses;
- free online open units; and
- free *Glossary of Metrology Terms*.

Ready for:

- apprenticeship programmes;
- national curricula; and
- workplace learning schemes.

Measurement just got simpler, and is now available to you **whenever you want and wherever you like – sign up now for free.**

<http://www.npl.co.uk/e-learning>



- Save time - Reduce time away from the job and fit training into busy work schedules
- Save money - Save travel costs and adjust training to your own schedule
- Take the classroom with you - Have your lessons anytime, anywhere
- Control your learning - Sequence your own learning and access only the materials you require
- Own your progression - Assess your progress and receive immediate feedback

C.6 Literature

C.6.1 Surface texture books

Blunt L A, Jiang X 2003 *Advanced techniques for assessment surface topography* (Butterworth-Heinemann: London)

Leach R K 2009 *Fundamental principles of engineering nanometrology* (Elsevier: Amsterdam)

Mainsah E, Greenwood J A, Chetwynd D G 2001 *Metrology and properties of engineering surfaces* (Kluwer Academic Publishers: Boston)

Smith G T 2002 *Industrial metrology: surfaces and roundness* (Springer-Verlag: London)

Thomas T R 1999 *Rough surfaces* 2nd edition (Imperial College Press: London)

Whitehouse D J 2010 *Handbook of surface and nanometrology* 2nd edition (CRC Press)

C.6.2 Associated good practice guides

Guide to the measurement of smooth surface topography using coherence scanning interferometry GPG 108

The measurement of rough surface topography using coherence scanning interferometry GPG 116

Calibration of the metrological characteristics of Coherence Scanning Interferometers (CSI) and Phase Shifting Interferometers (PSI) GPG 127

Calibration of the metrological characteristics of Imaging Confocal Microscopes (ICMs) GPG 128

Calibration of the metrological characteristics of stylus instruments GPG 129

C.7 Standards

C.7.1 Surface texture metrology

ISO 1302 (2002) Geometrical product specification (GPS) - Indication of surface texture in technical product documentation

ISO 3274 (1996) Geometrical product specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments

ISO 4287 (2000) Geometrical product specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters

ISO 4288 (1996) Geometrical product specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture

ISO 5436 part 1 (2000) Geometrical product specifications (GPS) – Surface texture: Profile method – Measurement standards – Part 1 Material measures

ISO 5436 part 2 (2012) Geometrical product specifications (GPS) – Surface texture: Profile method – Measurement standards – Part 2 Software measurement standards

ISO 13565 part 1 (1996) Geometrical product specifications (GPS) – Surface texture: Profile method; Surface having stratified functional properties – Part 1: Filtering and general measurement conditions

ISO 13565 part 2 (1996) Geometrical product specifications (GPS) – Surface texture: Profile method; Surface having stratified functional properties – Part 2: Height characterization using the linear material ratio curve

ISO 13565 part 3 (1998) Geometrical product specifications (GPS) – Surface texture: Profile method; surfaces having stratified functional properties – Part 3: Height characterization using the material probability curve

ISO 12085 (1996) Geometrical product specifications (GPS) – Surface texture: Profile method – Motif parameters

ISO 12179 (2000) Geometrical Product Specifications (GPS) -- Surface texture: Profile method -- Calibration of contact (stylus) instruments

ISO 16610 part 21 (2011) Geometrical product specifications (GPS) - Filtration - Part 21: Linear profile filters: Gaussian filters

C.7.2 General interest

PD 6461 (1995) Vocabulary of metrology – Part 1. Basic and general terms (international)

This standard has been withdrawn as it is based on the second edition of the International vocabulary of basic and general terms in metrology (VIM). A new 3rd edition of the VIM was published by ISO as ISO/IEC Guide 99:2007.

PD 6461 (1995) Vocabulary of metrology – Part 2. Vocabulary of legal metrology – fundamental terms

This standard has been withdrawn as it reproduces verbatim the International Vocabulary of Terms used in Legal Metrology (VIML) published by the International Organization of Legal Metrology (OIML). The OIML has published later editions of the VIML but PD 6461-2:1980

has not been revised in line with the OIML documents. The latest edition of the VIML was published in 2000 and is available to download free of charge from the OIML web site.

PD 6461 (1995) Vocabulary of metrology – Part 3. Guide to the expression of uncertainty in measurement

This standard has been withdrawn as it is based on the 1993 edition of the Guide to the expression of uncertainty in measurement (GUM). ISO has recently republished the 1995 (corrected) edition of the GUM as ISO/IEC Guide 98-3:2008.

PD 6461-4:2004 General metrology. Practical guide to measurement uncertainty

C.8 UKAS accredited laboratories for surface texture measurement

C.8.1 Surface texture

Trescal Limited

A member of the Trescal Limited Group

Calibration Laboratory, Muirton Way, Donibristle Industrial Estate, Donibristle, Dalgety Bay, KY11 9FZ

+44 (0)1383 646467

Website: www.trescal.co.uk/

Trescal Limited

A member of the Trescal Limited Group

Fulwood Road South, Fulwood Industrial Estate, Sutton-in-Ashfield, Nottingham, NG17 2JZ

+44 (0)1623 555110

Website: www.trescal.co.uk/

Trescal CMS

A member of the Trescal Limited Group

Greenfold Way, Leigh Commerce Park, Leigh, Greater Manchester, WN7 3XJ

+44 (0)1252 533 300

Website: www.trescal.co.uk/

Trescal Limited

A member of the Trescal Limited Group

Park Gate Close, Bredbury Park Way, Bredbury, Stockport, SK6 2SL

+44 (0)161 406 7878

Website: www.trescal.co.uk/

Trescal Limited

A member of the Trescal Limited Group

Sanders Building, Gunnels Wood Road, Stevenage, SG1 2AU

+44 (0)1438 772003

Website: www.trescal.co.uk/

Trescal CMS

A member of the Trescal Limited Group

Saxony Way, Blackbushe Business Park, Yateley, Hampshire, GU14 6GT

+44 (0)1252 533 300

Website: www.trescal.co.uk/

CoMech Metrology Limited

Metrology Division, Calibration House, Castings Road, Derby, United Kingdom, DE23 8YL

+44(0)1332 867700

Website: www.comech.co.uk/

G B Quality Assurance

Unit 9, Chancel Way, Moore Lane Industrial Estate, Birmingham, United Kingdom, B6 7AU

+44 (0) 121 356 7430

Trescal Limited

Saxony Way, Blackbushe Business Park, Yateley, Hampshire, United Kingdom, GU46 6GT

+44 (0)1252 533 300

Website: www.trescal.co.uk/

PowerKut Limited

23 Brindley Road Exhall, Coventry, West Midlands, United Kingdom, CV7 9EP

+44 (0) 24 7664 4661

Website: <http://www.powerkut.co.uk/>

Taylor Hobson

Calibration Laboratory, New Star Road, Leicester, United Kingdom, LE4 9JQ

+44 (0)116 276 3771

Website: www.taylor-hobson.com

Micron Metrology 2000 Limited

Eurolab House, Unit 10 Valepits Road, Garretts Green Industrial Estate, Birmingham, United Kingdom, B33 0TD

+44 (0)121 784 7498

Website: <http://www.micron-metrology.co.uk/>

Jaguar Land Rover Limited

Land Rover Calibration Centre, Block 71, 53S12/3, Land Rover Plant, Lode Lane, Solihull, West Midlands, United Kingdom, B92 8NW

+44 (0)121 700 3557

Website: www.landrover.com

Mitutoyo (UK) Limited

6 Banner Park, Wickmans Drive, Coventry, United Kingdom, CV4 9XA

+44 (0) 2476 426 316/317

Website: www.miyutoyo.co.uk

C.8.2 Surface texture, comparison specimens

Taylor Hobson

Calibration Laboratory, New Star Road, Leicester, United Kingdom, LE4 9JQ

+44 (0)116 276 3771

Website: www.taylor-hobson.com

C.8.3 Surface texture, measuring machines

Taylor Hobson

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+44 (0)116 276 3771

Website: www.taylor-hobson.com

C.8.4 Surface texture, reference standards

Taylor Hobson

Calibration Laboratory, New Star Road, Leicester, United Kingdom, LE4 9JQ

+44 (0)116 276 3771

Website: www.taylor-hobson.com

C.9 Other useful links

National Physical Laboratory, Mass and Dimensional Group

Hampton Road, Teddington, Middlesex TW11 0LW

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<http://www.npl.co.uk/science-technology/dimensional/>

British Standards Institute (BSI)

www.bsigroup.com

International Standards Organisation (ISO)

www.iso.ch/

United Kingdom Accreditation Service

21 - 47 High Street, Feltham, Middlesex TW13 4UN, UK

+44 (0)20 8917 8556

www.ukas.com

University of Huddersfield

School of Engineering

<http://www.hud.ac.uk/research/researchcentres/cimam/>