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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 13565-3 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification.*

ISO 13565 consists of the following parts under the general title *Geometrical product specifications (GPS) — Surface texture: Profile method; Surfaces having stratified functional properties*:

— *Part 1: Filtering and general measurement conditions*

— *Part 2: Height characterization using the linear material ratio curve*

— *Part 3: Height characterization using the material probability curve*

Annex A forms an integral part of this part of ISO 13565. Annexes B to F are for information only.

Introduction

This part of ISO 13565 is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences the chain link 2 of the chains of standards on roughness profile and primary profile.

For more detailed information on the relation of this standard to the GPS matrix model see annex E.

This part of ISO 13565 provides a numerical characterization of surfaces consisting of two vertical random components, namely, a relatively coarse "valley" texture and a finer "plateau" texture. This type of surface is used for lubricated, sliding contact, for example in cylinder liners and fuel injectors. The calculations necessary to determine the parameters *Rpq*, *Rvq*, and *Rmq* (*Ppq*, *Pvq*, and *Pmq*) used to characterize these two components separately involves the generation of the material probability curve, the determination of its linear regions, and the linear regressions through these regions.

The parameters are undefined for surfaces not consisting of two such components.

Geometrical Product Specifications (GPS) — Surface texture: Profile method; Surfaces having stratified functional properties —

Part 3:
Height characterization using the material probability curve

1 Scope

This part of ISO 13565 establishes the evaluation process for determining parameters from the linear regions of the material probability curve, which is the Gaussian representation of the material ratio curve. The parameters are intended to aid in assessing tribological behaviour, for example of lubricated, sliding surfaces, and to control the manufacturing process.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 13565. At the time of publication, the editions indicated were valid. All Standards are subject to revision, and parties to agreements based on this part of ISO 13565 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 1302:1992, *Technical drawings — Methods of indicating surface texture.*

ISO 3274:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Nominal characteristics of contact (stylus) instruments.*

ISO 4287:1997, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters.*

ISO 13565-1:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method; Surfaces having stratified functional properties — Part 1: Filtering and general measurement conditions.*

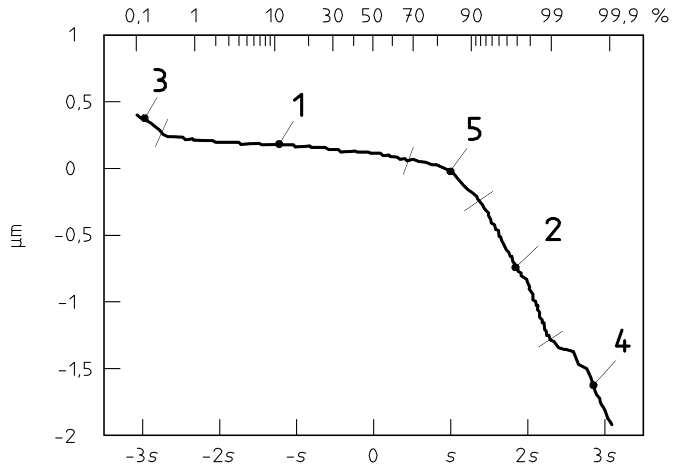
ISO 13565-2:1996, *Geometrical Product Specifications (GPS) — Surface Texture: Profile method; Surfaces having stratified functional properties — Part 2: Height characterization using the linear material ratio curve.*

3 Definitions

For the purposes of this part of ISO 13565, the definitions given in ISO 3274, ISO 4287, ISO 13565-2 and the following apply.

3.1
material probability curve
a representation of the material ratio curve in which the profile material length ratio is expressed as Gaussian probability in standard deviation values, plotted linearly on the horizontal axis

NOTE — This scale is expressed linearly in standard deviations according to the Gaussian distribution. In this scale the material ratio curve of a Gaussian distribution becomes a straight line. For stratified surfaces composed of two Gaussian distributions, the material probability curve will exhibit two linear regions (see 1 and 2 in figure 1).



Key

1 Plateau region

2 Valley region

3 Debris or outlying peaks in the data (profile)

4 Deep scratches or outlying valleys in the data (profile)

5 Unstable region (curvature) introduced at the plateau to valley transition point based on the combination of two distributions

Figure 1 — Material probability curve

3.2
Rpq (*Ppq*) **parameter**
slope of a linear regression performed through the plateau region

See figure 2.

NOTE — *Rpq* (*Ppq*) can thus be interpreted as the *Rq* (*Pq*)-value (in micrometres) of the random process that generated the plateau component of the profile.

3.3
Rvq (*Pvq*) **parameter**
slope of a linear regression performed through the valley region

See figure 2.

NOTE — *Rvq* (*Pvq*) can thus be interpreted as the *Rq* (*Pq*)-value (in micrometres) of the random process that generated the valley component of the profile.

3.4
Rmq (*Pmq*) **parameter**
relative material ratio at the plateau to valley intersection

See figure 2.

4 Procedure

The roughness profile used for determining the parameters *Rpq*, *Rvq* and *Rmq* shall be calculated in accordance with ISO 13565-1. This roughness profile is different from that in ISO 4287. The profile for determining the parameters *Ppq*, *Pvq* and *Pmq* shall be the primary profile.

Three non-linear effects can be present in the material probability curve as shown in figure 1 for measured surface data from a two-process surface. These effects shall be eliminated by limiting the fitted portions of the material probability curve, using only the statistically sound, Gaussian portions of the material probability curve excluding a number of influences.

In figure 1 the non-linear effects originate from:

— debris or outlying peaks in the data (profile) (labelled 3);

— deep scratches or outlying valleys in the data (profile) (labelled 4); and

— unstable region (curvature) introduced at the plateau to valley transition point based on the combination of two distributions (labelled 5).

These exclusions are intended keep the parameters more stable for repeated measurements of a given surface. Figure 2 shows a profile with its corresponding material probability curve and its plateau and valley regions and the parts of the surface that defines the two regions. The profile has a peak that is outlying and the figure shows how it does not influence the parameters. Figure 2 also shows how the bottom parts of the deepest groves, which will vary significantly depending on where the measurements are made on a surface, are disregarded when determining the parameters.

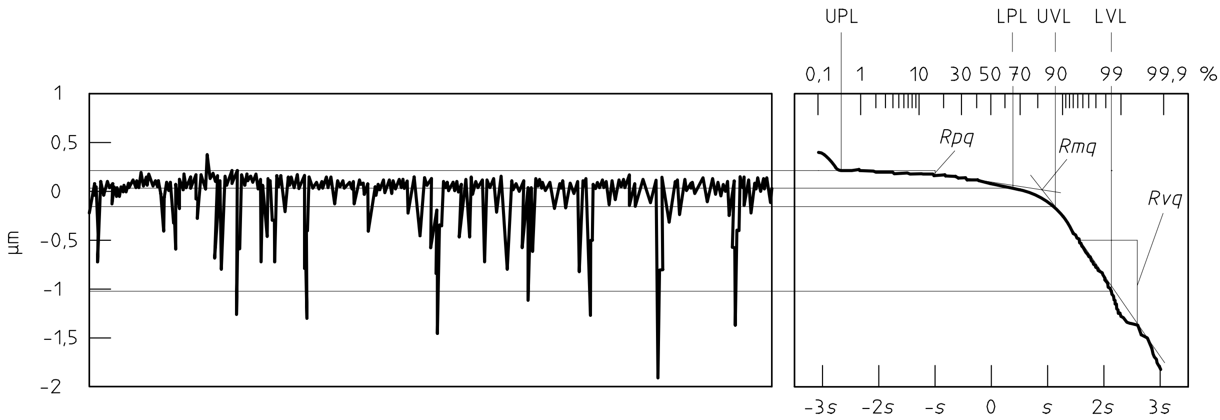


Figure 2 — Roughness profile with its corresponding material probability curve and the regions used in the definitions of the parameters *Rpq*, *Rvq*, and *Rmq*

5 Measurement process requirements

The following criteria are designed to ensure that the profile represents a proper two-process surface and that the measuring process is adequate for calculating a stable material probability curve resulting in reliable parameter values. These criteria shall be met in order for the parameters *Rpq*, *Rvq*, and *Rmq* (*Ppq*, *Pvq*, and *Pmq*) to be defined:

— The instrument shall be capable of measuring a value of *Rq* from an optical flat that is less than 30 % of the nominal value of *Rpq* (*Ppq*).

— The vertical resolution of the material probability curve shall be such that at least 40 classes fall within the linear plateau and linear valley regions respectively.

— The digital data density of the material probability curve shall be such that at least 100 profile ordinates fall within the linear plateau and linear valley regions respectively.

— The ratio *Rvq*: *Rpq* (*Pvq*: *Ppq*) shall be at least 5.

— The conic section regressions result in a hyperbolic solution (see annex A).

If the profile does not satisfy the above criteria, a suitable warning message shall give the reason for the failure.

6 Drawing indications

The parameters specified in this part of ISO 13565 shall be indicated on drawings in accordance with ISO 1302.

Annex A
(normative)

Procedures for determining the limits of the linear regions

Clauses A.1 through A.3 specify the procedures for determining the upper plateau limit, UPL, and the lower valley limit, LVL. Clauses A.4 through A.6 specify the procedures for determining the lower plateau limit, LPL, and the upper valley limit, UVL . Clause A.7 specifies the procedure for determining the calculation of parameters.

A.1 Initial conic fit

A conic section is initially fitted through the material probability curve since it is a very good approximation of the expected form of the material probability curve of surfaces consisting of two vertical random components. This initial conic fit provides a framework for subsequent operations on the material probability curve.

Fit a conic section

$$z = Ax^2 + Bxz + Cz^2 + Dx + E$$

where

z is the profile height;

x is the material probability expressed in standard deviations;

through the entire curve (see figure A.1).

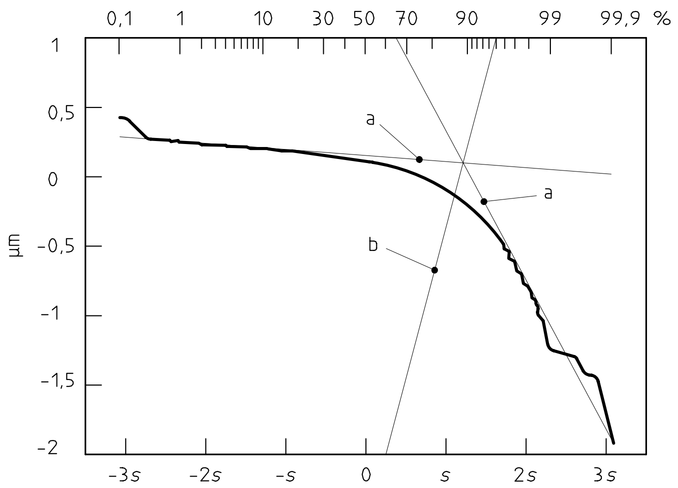


Figure A.1 — Conic section based on the entire material probability curve

A.2 Estimation of plateau to valley transition

Determine the asymptotes of the conic section (lines designated "a" in figure A.1). Bisect the asymptotes with a line (line designated "b" in figure A.1). The intersection of this line with the conic section serves as an initial estimate of the plateau to valley transition (see A in figure A.2).

NOTE — Graphically the bisector line may appear to be at a improper angle (see figure A.1). This is because of the different scaling of the two axis on figure A.1. See also clause A.4 and annex D for the normalized material probability curve, where the bisector line appears consistent.

A.3 Determination of UPL and LVL

The second derivative is computed at each point of the material probability curve starting at the transition point "c" and working upward through the plateau region and downward through the valley region.

The second derivative at each point is computed using a "window" of 0,05 standard deviations ($\pm$ 0,025 $\times s$ around the point at which the derivative is to be recorded). See B in figure A.2.

NOTE — The number of points within the window will vary as it is passed through the curve.

For the valley region and the plateau region individually:

- find 25 % of the number of points to one side of the point "c"; call this value i;
- working out from point "c", the standard deviation, s_i, is computed for the second derivative values using i points on one side;
- the value of the second derivative at the next point (D_{i+1}) is divided by the standard deviation, s_i:

$$T = \frac{D_{i+1}}{s_i}$$

- if $T \leqslant 6$, increment i by 1, recompute s_i and T;
- if $T > 6$, data point i is the limit of that region (UPL for the plateau region and LVL for the valley region, respectively). See also C in figure A.2.

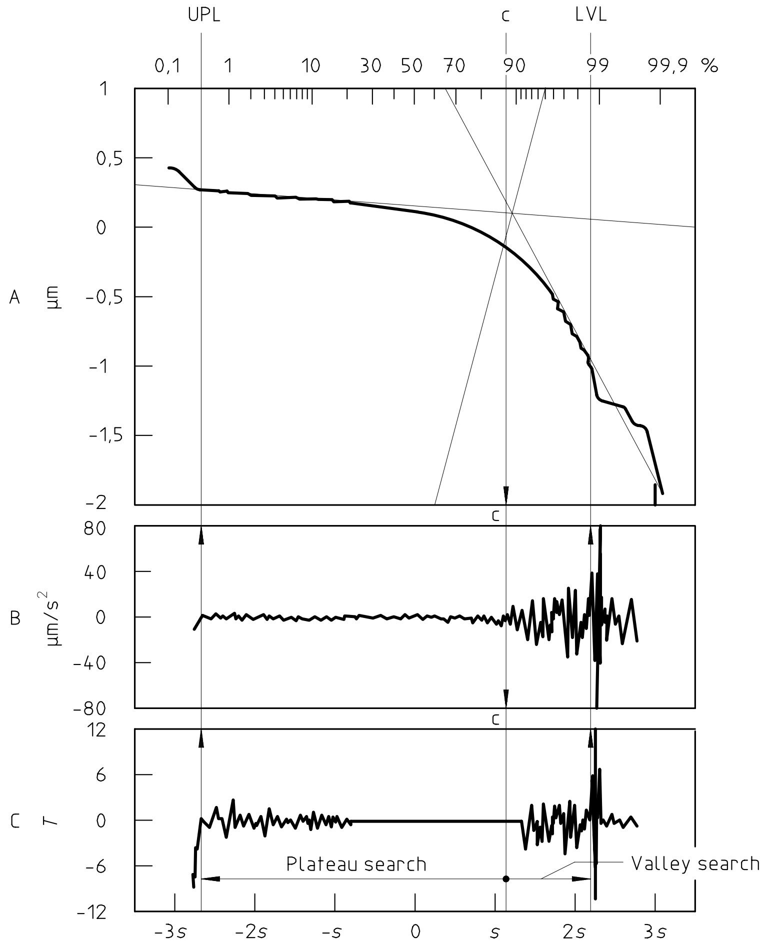


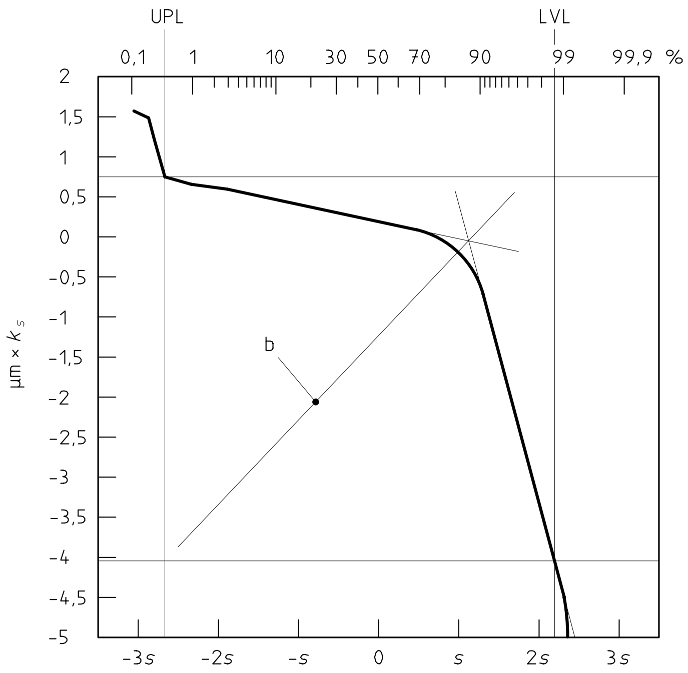
Figure A.2 — Bisection of the asymptotes is the initial transition point between the two regions of the material probability curve and the corresponding second derivatives

A.4 Normalization of the bounded region

The Z-axis of the material probability curve is normalized such that the bounded region (region between UPL and LVL) is "square" (see annex D). This insures consistent bisection of the conic section asymptotes (see figure A.3).

A.5 Second conic section fit

The conic section is now regressed through the region within UPL and LVL. The asymptotes are constructed (see figure A.3).

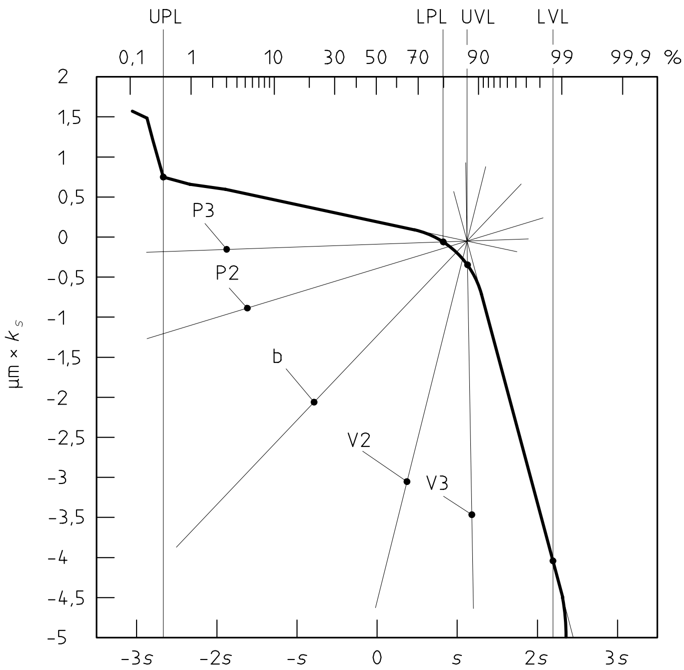


NOTE — For k_s, see annex D.

Figure A.3 — Conic section determined within the upper plateau limit, UPL, and the lower valley limit, LVL — Normalized material probability curve

A.6 Determination of LPL and UVL

To determine the lower plateau limit, LPL , and the upper valley limit, UVL , the asymptotes are bisected three times (b: first time; P2 and V2: second time; P3 and V3: third time). The intersection of these lines (P3 and V3) with the conic section of the material probability curve determines the LPL and UVL (see figure A.4).



NOTE — For k_s, see annex D.

Figure A.4 — Determination of the lower plateau limit, LPL, and the upper valley limit, UVL — Normalized material probability curve

A.7 Calculation of parameters

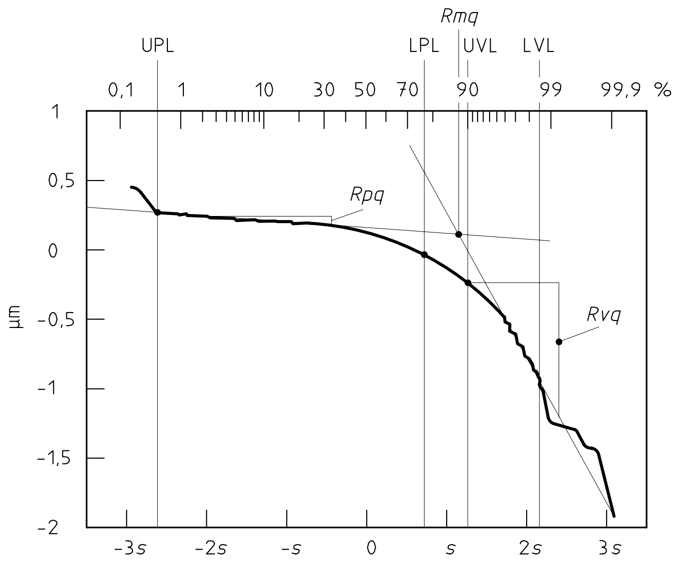
A linear regression is then performed within each region of the original, non-normalized material probability curve (see figure A.5).

Rpq (*Ppq*) is the slope of a linear regression ($z = A_p s + B_p$) performed through the plateau region. *Rpq* (*Ppq*) can thus be interpreted as the *Rq*-value (in micrometres) of the random process that generated the plateau component of the profile.

Rvq (*Pvq*) is the slope of a linear regression ($z = A_v s + B_v$) performed through the valley region. *Rvq* (*Pvq*) can thus be interpreted as the *Rq*-value (in micrometres) of the random process that generated the valley component of the profile.

Rmq (*Pmq*) is the bearing ratio at the plateau to valley intersection. That is:

$$Rmq = \frac{B_v - B_p}{A_p - A_v}$$



Rpq = 0,050 µm

Rvq = 0,869 µm

Rmq = 84,9 %

Figure A.5 — Plateau and valley regions for the linearization of the material probability with its parameters

Annex B
(informative)

Background information

B.1 General

Among the most critical tribological surface textures are stratified surfaces. The most common of these are manufactured by superposing two processes. This texture type is commonly found in lubricated, sliding interfaces where the specification and control of surface texture can have serious implications regarding factors such as leakage, scuffing, and wear.

In order to gain an understanding of two-process surfaces and their relationship to performance they should be characterized in a descriptive, meaningful manner. Moreover, the independent components of the surfaces should be characterized descriptively and independently.

While the method of characterization described in this annex applies to two-process textures of many origins, it was developed for the characterization of the common manufacturing process known as "plateau-honing". Plateau-honing is typical in internal combustion cylinder bores and has been shown to enhance performance while reducing "running-in" times. In this manufacturing process the independent aspects of the surface texture are:

a) the roughness of the initial coarse texture which establishes the surface's valleys,

b) the roughness of the fine texture which removes the upper portion of the coarse texture, and

c) the depth at which the fine texture truncates the coarse texture.

This part of ISO 13565 presents a parametric approach based on the Gaussian model whereby the three independent profile aspects can be independently measured as the process that generated the coarse texture's Rq roughness, the process that generated the fine texture's Rq roughness, and the material ratio at which the fine texture truncates the coarse texture.

B.2 Height characterization using the material probability curve

Two-process textures are, in general, the result of the combination of two Gaussian or near-Gaussian textures. Thus, the first step in an independent characterization of the two processes is to model of each component as a Gaussian waveform (see figure B.1).

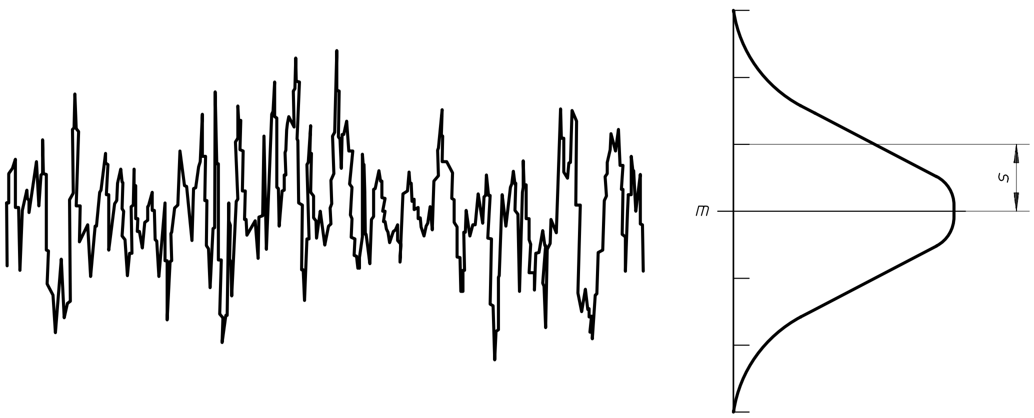


Figure B.1 — Gaussian characterization of a random profile

The characterization of normally distributed (Gaussian) data is commonly based on a mean value, m, and a standard deviation, s. In statistical applications, the sample standard deviation is computed as follows:

$$s = \sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}}$$

This is very similar to the Rq parameter:

$$Rq = \sqrt{\frac{\sum (y_i - \bar{y})^2}{n}}$$

Thus, for large values of n:

$$Rq \approx s$$

A graphical alternative to the above equation involves plotting the cumulative distribution (the mathematical equivalent to the material ratio curve) of the data points on normal (Gaussian) probability paper. In this graphical approach, the cumulative distribution of a Gaussian data forms a single, straight line. The slope of the line is the standard deviation (and thus Rq roughness) of the data and the 50 % (0 standard deviation) crossing is the mean height.

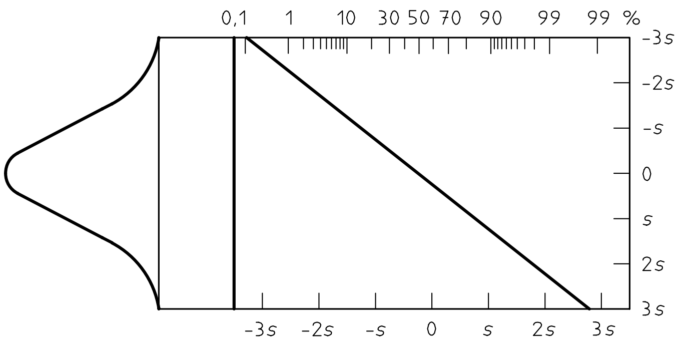


Figure B.2 — Analysis using probability paper

Gaussian probability paper, as in figure B.2, exhibits a linear Y-axis in units of the measured values and a linear X-axis in terms of cumulative standard deviations. However, it is often useful to display corresponding cumulative percentages on the X-axis although they are non-linear.

B.3 Application to two-process surface profile data

For normally distributed profile data, ($Rsk \approx$ 0,0, $Rku \approx$ 3,0) a probability-plotted material ratio curve can be used to graphically determine Rq. The use of probability paper for the analysis of single-process textures may not be interesting, however, for two-process textures, the benefits of the probability approach become apparent.

Figure B.3 displays the components of two-process textures and their corresponding probability-plotted material ratio curves. The rough, valley-making process (A in figure B.3) generates a relatively steep line in the probability-plotted material ratio curve (implying a relatively large Rq). Similarly, the finer texture component (B in figure B.3) makes a more shallow line (implying a relatively smaller Rq).

The power of probability analysis becomes apparent when these two textures are combined as C in figure B.3. In this profile, the deepest valleys of the original "rough" surface are still present, as well as the lower portion of steep line on the probability-plotted material ratio curve. The upper portion of "rough" profile has been removed and replaced with the finer texture and thus on the probability graph we find the upper portion of the steep line replaced by the more shallow line.

In practice, the profiles A and B shown in figure B.3 are not measured; only the two-process texture (C in figure B.3) is measured. However, since this profile contains evidence of both processes, both can still be described via the probability-plotted material ratio curve.

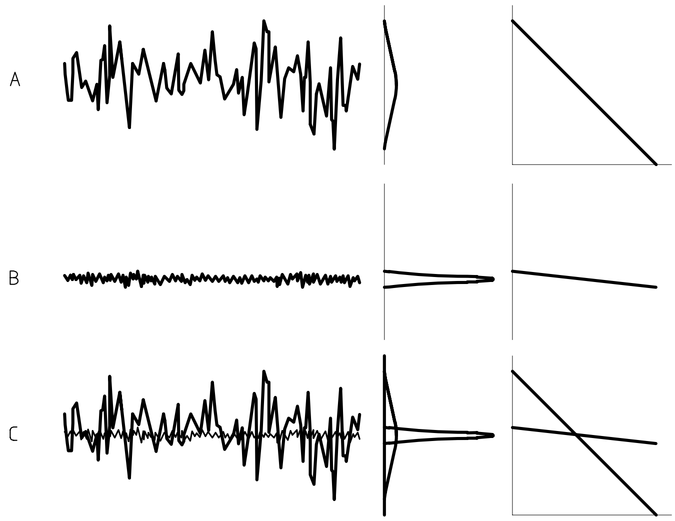


Figure B.3 — Probability analysis of two-process surface texture

Given the profile and probability plot in figure B.4, it can be determined that the plateau *Rq* value (designated *Rpq*) is 0,047 µm and the valley *Rq* roughness (designated *Rvq*) is 0,871 µm.

In addition to the ability to distinguish between the two roughness components of the two-process profile, the probability approach can also provide insight into the placement of the fine texture within the rough texture. This is achieved by determining the material ratio at the point of intersection between the plateau line and the valley line. In the data shown in figure B.4, the material ratio at the plateau to valley transition (designated *Rmq*) is 84,8 %.

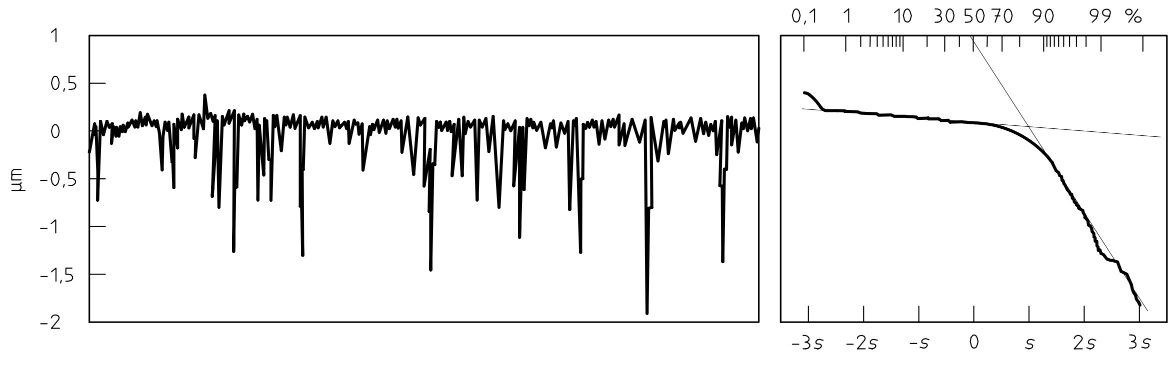


Figure B.4 — Two-process profile and probability-plotted material ratio curve

B.4 Process control

The Gaussian approach provides a direct indication of changes in surface texture. The three independent parameters are directly related to the three independent process controls.

The three probability parameters independently represent the three components of the plateau honing operation. This allows process changes to be directly monitored. When a probability parameter moves out of the control limits, the manufacturing engineer can move directly to the responsible component in the manufacturing process. Furthermore, the linear independence allows manufacturing process components to be studied and tested statistically without mathematical interactions between parameters.

B.5 Conclusion

The cumulative Gaussian probability distribution serves as an effective tool for the analysis of two-process surface texture. The parameters extracted from this methodology are linearly independent and are directly related to the independent components of the surface. Using this approach engineers can begin to understand the individual components of a profile rather than averaging over the entire profile. With this understanding, many advances can be made in the design of functional surface textures and process development and control associated with generating functional surfaces.

Annex C
(informative)

Determination of UPL and LVL via second derivatives

In order to provide more robust determination of the linear regions of the material probability curve, the influences of statistically outlying peaks and valleys should be removed. These profile attributes manifest themselves as non-linear regions near the upper and lower extremes (respectively) of the material probability curve which should be excluded before any analysis to ensure robustness.

The chosen method for determining these non-linear regions is based on determining abrupt changes in the local curvature of the material probability curve. The second derivative of the material probability curve is the mathematical description of the local curvature. In the linear regions of the material probability curve the second derivative is near zero. However, in the extremes of the material probability curve, where the above mentioned non-linearities occur, the second derivatives increase in absolute magnitude. The computation of the derivative at a given point involves a linear regression in a region about the point. For the purposes of this part of ISO 13565, the width of the region is to be fixed at 0,05 standard deviations (enclosing 0,025 standard deviations on each side of the given point). The number of points enclosed in this region will vary as derivatives are computed along the curve (see figure C.1).

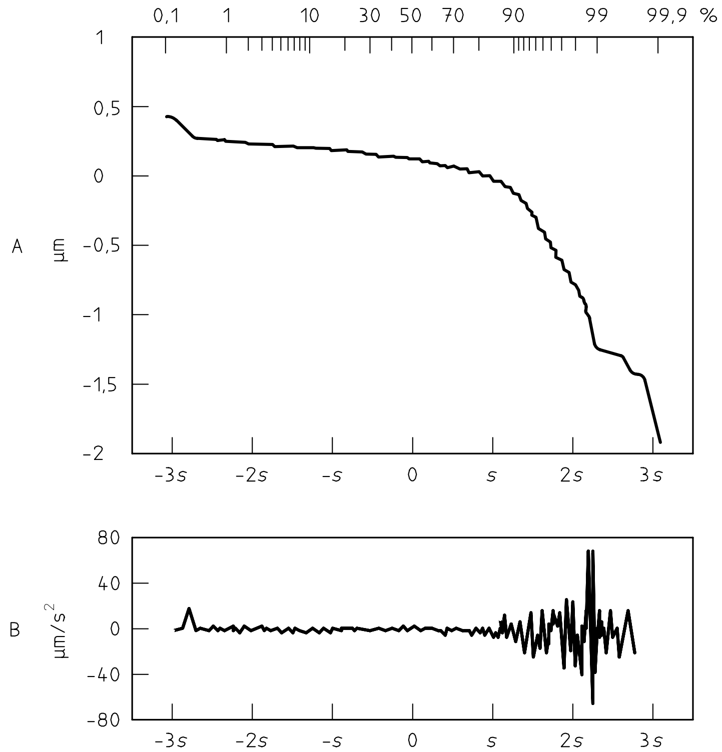


Figure C.1 — Material probability curve and second derivatives

To determine the points along the second derivative plot where significant increases in absolute magnitude occur, a starting point, "c", is determined through the fitting of a conic section through the entire material probability curve and bisecting its asymptotes. The intersection point of the bisector and the material probability curve determines this starting point. This starting point, "c", is used to initiate a leftward (plateau) search for the UPL and also for a rightward (valley) search for the LVL (see figure C.2).

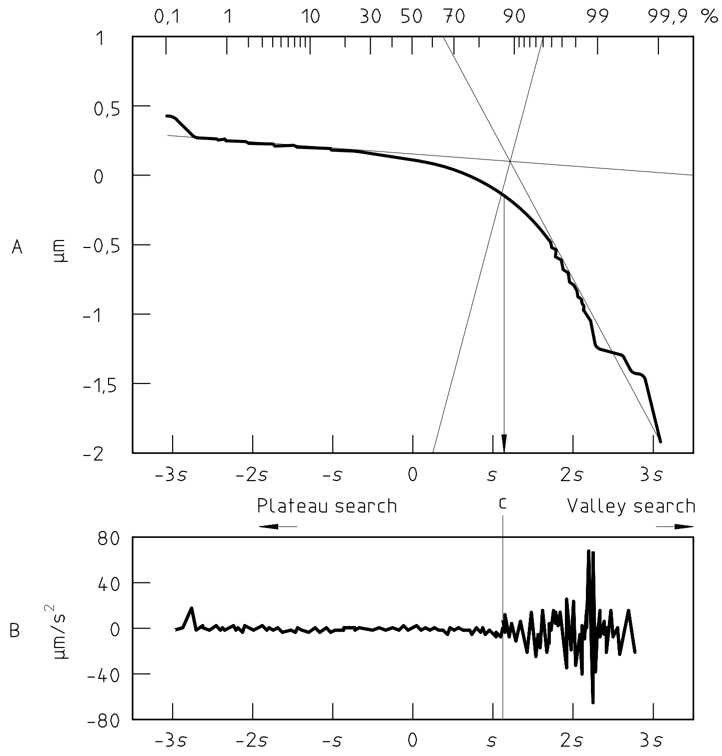


Figure C.2 — Material probability curve with starting point and search directions

The search procedure for each limit (UPL and LVL) is initiated at the starting point "c" and progresses outward in the direction of the limit to be determined. The search continues until the second derivative of the next point significantly exceeds the distribution of second derivatives of previous points on that side of the starting point "c". This is accomplished by comparing the second derivative in the next point to the standard deviation of the second derivatives of the previous points. If the absolute value of the second derivative in the next point exceeds 6 times the standard deviation of the second derivatives determined from the previous points then the current point becomes either the UPL or LVL. If the next point does not exceed 6 standard deviations of the second derivatives of the previous points, it is combined with the previous points to generate a new standard deviation and the useful region of interest is thus expanded by one point.

In order to start the search with a stable standard deviation value, the first 25 % of the points in a given search direction is used.

NOTE — Experiments have shown that for two-process surfaces which meet the requirements of clause 4, the linear regions are at least 25 % of each side of the starting point.

The search begins at the next point and terminates when the next point exceeds 6 standard deviations (one sided).

Figure C.3 shows the value of the second derivative of the "next point" (D_{i+1}) relative to the standard deviation the second derivatives of the previous point s_i:

$$T = \frac{D_{i+1}}{s_i}$$

This was generated in each direction from the starting point "c" and the values for the 25 % regions were set to zero for plotting purposes.

NOTE — The 25 % region is made up of one fourth of the data points on each side. The data points are not equally spaced and therefore this region is not one fourth of the length of the plot on each side.

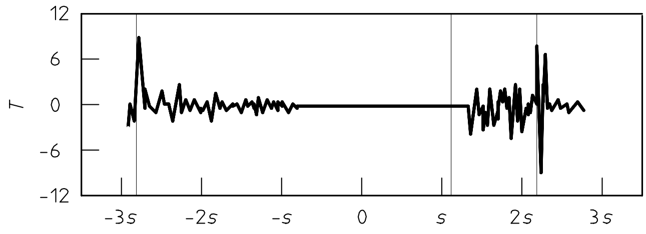


Figure C.3 — Normalized second derivatives

Annex D
(informative)

Normalization of the bounded material probability curve

The upper plateau limit, UPL, and the lower valley limit, LVL, bound the central, significant region of the material probability curve. This bounded region (region between UPL and LVL) encloses the plateau and valley portions, as well as the plateau to valley transition region. A conic section is fitted to the curve in order to determine the transition and ultimately the plateau and valley regions. From this conic section, asymptotes are constructed and subsequently bisected.

The bisection of lines involves knowledge of two parameters for each asymptote line: the slope and intercept. In the material probability curve, these parameters are a function of the probability scale on the X-axis and a function of the vertical magnitude of the profile (expressed in micrometers) on the Y-axis. Since a different vertical magnification results in different bisectors, even though the profiles may be identical, it is necessary to use a stable procedure that results in consistent bisectors independently of the vertical scale.

For the purpose of overcoming the variations in the bisectors, which will ultimately determine LPL and UVL, the vertical axis of the material probability curve is normalized. This normalization is such that the enclosed UPL - LVL region encompasses the same number of vertical units as encompasses standard deviations on the probability scale.

In figure D.1 (example), the material probability curve encloses 4,8s on the probability scale and 1,12 µm on the vertical height scale between the UPL and the LVL.

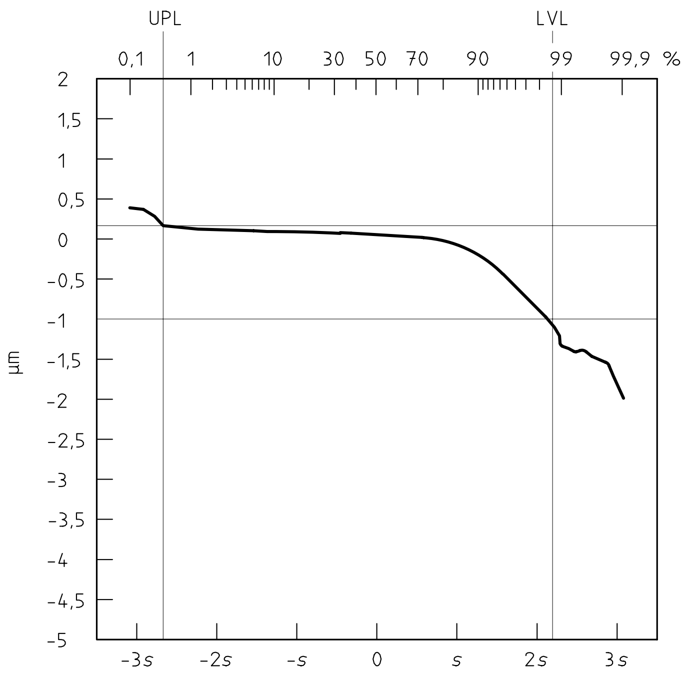


Figure D.1 — Non-normalized material probability curve

This plot is normalized (scaled) in the vertical direction by a factor of (k_s = 4,8/1,12 = 4,29), thus bounding the region of interest by 4,8s on the probability axis and by 4,8 units of height on the vertical axis.

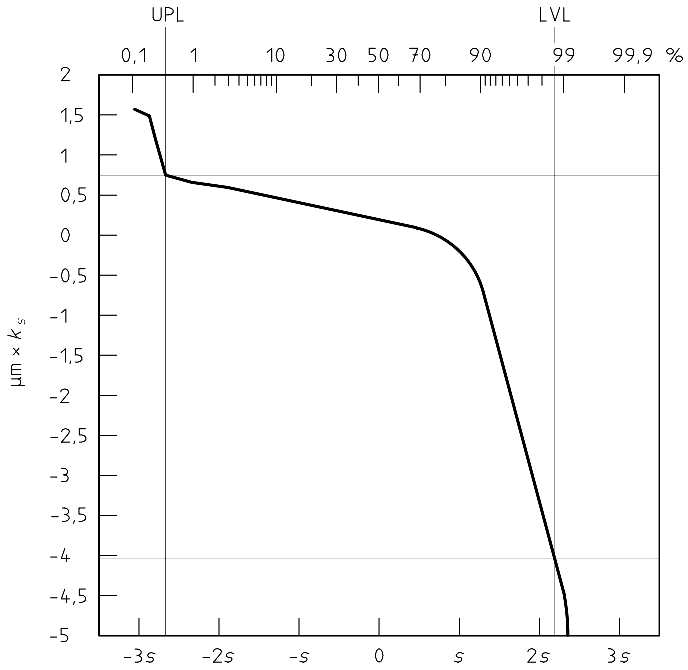


Figure D.2 — Normalized material probability curve

At this point the conic section is regressed through the data as indicated in clause A.5 and bisected according to clause A.6 to determine the LPL and the UVL. Upon determination of the position of these points along the probability axis, the material probability curve can be re-scaled to vertical heights prior to the plateau and valley linear regressions described in clause A.7.

Annex E
(informative)

Relation to the GPS matrix model

For full details about the GPS matrix model, see ISO/TR 14638.

E.1 Information about this part of ISO 13565 and its use

This part of ISO 13565 specifies a method for determining a set of parameters, based on the material probability curve, to be used for the evaluation of the valley suppressed roughness profile defined in ISO 13565-1. It is based on a two layer surface model, evaluating the plateaus and the valleys separately.

The parameters are intended to aid in assessing the operational behaviour of highly mechanically stressed surfaces.

The roughness profile used for determining these parameters are calculated in accordance with ISO 13565-1.

E.2 Position in the GPS matrix model

This part of ISO 13565 is a general GPS standard, which influences the chain link 2 of the chains of standards on roughness profile and primary profile in the *General GPS matrix*, as graphically illustrated in figure E.1.

Fundamental GPS standards

Global GPS standards

General GPS matrix						
Chain link number	**1**	**2**	**3**	**4**	**5**	**6**
Size						
Distance						
Radius						
Angle						
Form of line independent of datum						
Form of line dependent on datum						
Form of surface independent of datum						
Form of surface dependent on datum						
Orientation						
Location						
Circular run-out						
Total run-out						
Datums						
Roughness profile						
Waviness profile						
Primary profile						
Surface imperfections						
Edges						

Figure E.1

E.3 Related standards

The related International Standards are those of the chains of standards indicated in figure E.1.

Annex F
(informative)

Bibliography

[1] ISO 4288:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture.*

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[5] *International vocabulary of basic and general terms in metrology (VIM)*. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 2nd edition, 1993.