TECHNICAL REPORT

ISO/TR 10064-4

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1998-10-15

Cylindrical gears — Code of inspection practice

Part 4:
Recommendations relative to surface texture and tooth contact pattern checking

Engrenages cylindriques — Code pratique de réception —

Partie 4: Recommandations relatives à la rugosité de surface et au contrôle de la marque de portée

Reference number
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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.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is a future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 10064-4, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 60, *Gears*.

ISO 10064 consists of the following parts, under the general title *Cylindrical gears — Code of inspection practice*:

— *Part 1: Inspection of corresponding flanks of gear teeth*

— *Part 2: Inspection related to radial composite deviations, runout, tooth thickness and backlash*

— *Part 3: Recommendations relative to gear blanks, shaft centre distance and parallelism of axes*

— *Part 4: Recommendations relative to surface texture and tooth contact pattern checking*

Introduction

In the course of revising ISO 1328:1975, it was decided that descriptions and numerical values relative to surface texture and tooth contact pattern checking should be published under separate cover as a Technical Report, type 3. For the general replacement of ISO 1328:1975, a system of documents as listed in clause 2 (References), together with this Technical Report, has been established.

Cylindrical gears — Code of inspection practice

Part 4:
Recommendations relative to surface texture and tooth contact pattern checking

1 Scope

This part of ISO/TR 10064 provides recommendations on measurement considerations for surface roughness and tooth contact pattern checking of gear flanks.

Numerical values given in this document are not to be regarded as strict ISO accuracy criteria, but may serve as a guide for mutual agreements, for steel or iron components.

2 References

ISO 53:1998*, Cylindrical gears for general and heavy engineering — Standard basic rack tooth profile.*

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

ISO 1328-1:1995, *Cylindrical gears — ISO System of accuracy — Part 1: Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth.*

ISO 1328-2:1996, *Cylindrical gears — ISO System of accuracy — Part 2: Definitions and allowable values of deviations relevant to radial composite deviations and runout.*

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

ISO 11562:1996, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Metrological characteristics of phase correct filters.*

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 Symbols and definitions

3.1 Symbols

Symbols used for deviations of individual element measurements are composed of lower case letters, such as "*f*", with subscripts, whereas symbols used for "total" deviations, which may represent combinations of several individual element deviations, are composed of capital letters, such as "*F*", also with subscripts. Only symbols for quantities used in this part of ISO/TR 10064 are given in Table 1.

Table 1 — Symbols used within ISO/TR 10064-4

Symbol	Term	Units
$f_{w\beta}$	amplitude of undulation	µm
b_{c1}	larger length of contact pattern	%
b_{c2}	smaller length of contact pattern	%
h_{c1}	larger height of contact pattern	%
h_{c2}	smaller height of contact pattern	%
lr	sampling length for roughness profile	mm
ln	evaluation length (Default is normally *ln* = 5 x *lr*	mm
	— see ISO 4287:1997, table C.2 and ISO 4288:1996, 4.4.)	
Mr	material length	mm
*Mr*1 & *Mr*2	material portion	%
Ra	arithmetical mean deviation of the roughness profile	µm
Rk	core roughness depth	µm
Rpk	reduced peak height	—
Rvk	reduced valley depth	—
Rz	maximum height of the roughness profile (see ISO 4287)	µm
Z(x)	ordinate value	µm
λ	wavelength	mm
λc	wavelength cutoff (and short wave cut-off for waviness)	mm
λs	short wavelength cutoff for roughness	mm

3.2 Terms and definitions

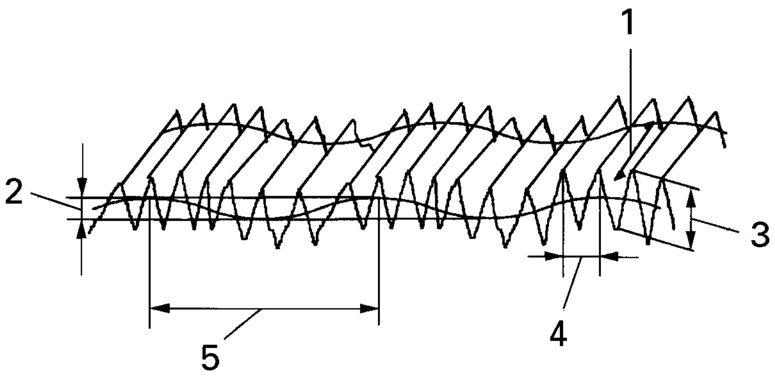
3.2.1 General terms

3.2.1.1
surface lay
The direction of the predominant surface pattern (see Figure 1a).

NOTE Surface lay is ordinarily determined by the production method used.

3.2.1.2
roughness
The irregularities of the roughness profile (see 3.2.2.1). It is the component of surface texture inherent in the production process but excluding waviness and deviation of form.

3.2.1.3
waviness
The irregularities of the waviness profile (see 3.2.2.2). That component of surface texture upon which roughness is superimposed (see Figures 1a, 1b, 1c). In general, for machined gear tooth surfaces the waviness spacing is significantly greater than the roughness spacing.



Key

1 Lay (direction of dominant pattern)

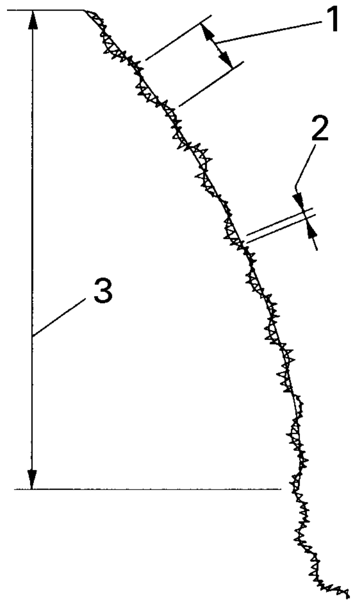
2 Waviness

3 Roughness

4 Roughness spacing

5 Waviness spacing

Figure 1a — Surface characteristics and terms



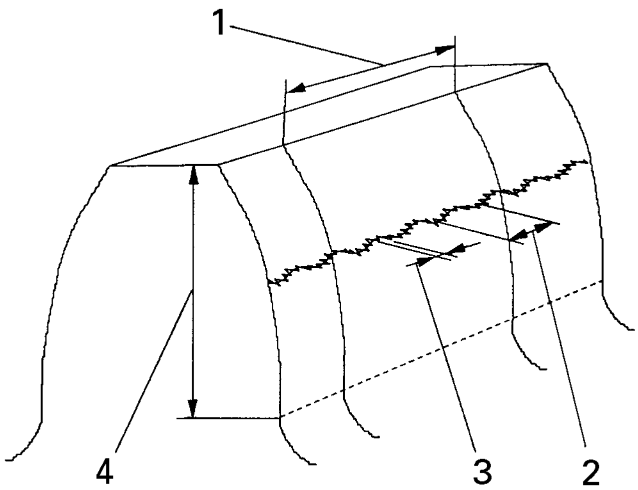
Key

1 Waviness spacing

2 Roughness spacing

3 Working tooth depth

Figure 1b — Enlarged example of the surface texture profile of an involute tooth



Key

1 Distance equal to working tooth depth

2 Waviness

3 Roughness

4 Working tooth depth

Figure 1c — Enlarged example of the surface texture profile along a tooth

3.2.2 Terms associated with the assessment of surface profile

3.2.2.1
roughness profile
The transmission band for roughness profiles is defined by the λc and λs profile filters (see ISO 11562:1996, clause 3), see Figure 1.

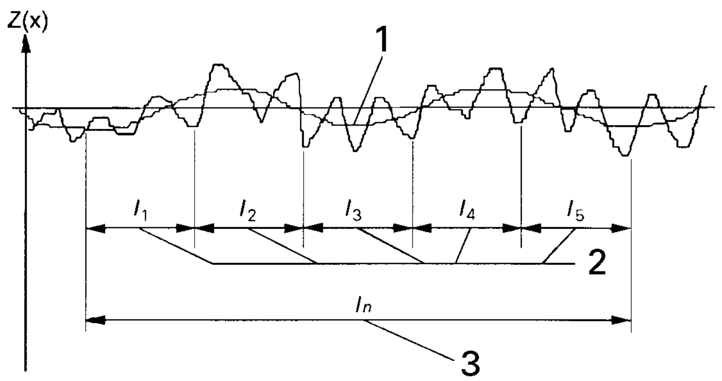
NOTE 1 The roughness profile is the basis for evaluation on the roughness profile parameters.

NOTE 2 The default relationship between λc and λs is given in ISO 11562:1996, clause 3.2.

3.2.2.2
waviness profile
The periodic part of the long wave component after the use of the profile filter λc.

3.2.2.3
mean line for the roughness profile
The mean line is the long wave profile component suppressed by the profile filter λc (see ISO 11562:1996, 3.2.1).

NOTE The mean line for the roughness profile is the reference line from which the profile ordinate $Z(x)$ is measured, see Figure 2.



Key
1 Mean line
2 Sampling lengths
3 Evaluation length

Figure 2 — Measurement lengths

3.2.2.4
ordinate value
The height of the assessed profile at any position x.

3.2.2.5
sampling length, *lr*, for roughness
The length in the direction of the x-axis used for identifying the irregularities characterizing the profile under evaluation. The sampling length for roughness *lr* is numerically equal to the characteristic wavelength of the profile filter λc (see ISO 4287).

3.2.2.6
evaluation length, *ln*
The length in the direction of the x-axis used for assessing the profile under evaluation. The evaluation length may contain one or more sampling lengths (see ISO 4287).

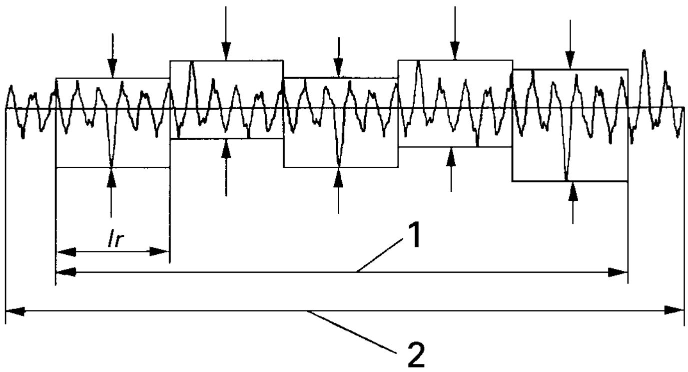
3.2.2.7
cut-off wavelength, λc, of profile filters (phase, correct, gaussian)
The wave length of a sinusoidal profile of which 50% of the amplitude is transmitted by the profile filter (see ISO 11562).

3.2.2.8
cut-off ratio
The ratio of the long wave length characteristic cut-off to the short wave length characteristic cut-off of a given transmission band (see ISO 11562).

3.2.3 Terms related to surface roughness parameters

3.2.3.1
maximum heights of roughness profile, *Rz*
The sum of the height of the largest profile peak height, *Zp*, and the largest profile valley depth, *Zv*, within a sampling length (see ISO 4287:1997, 4.1.3 and Figure 9).

NOTE Usually this parameter is measured as a mean value of five adjacent sampling lengths. The evaluation length then consists of five sampling lengths (see Figure 3).



Key
1 Evaluation length, *ln*
2 Traversed length

Figure 3 — Maximum height of roughness profile

3.2.3.2
arithmetical mean deviations of the roughness profile, *Ra*
The arithmetical mean of the absolute ordinate values *Z*(x) within a sampling length (see ISO 4287:1997, 4.2.1).

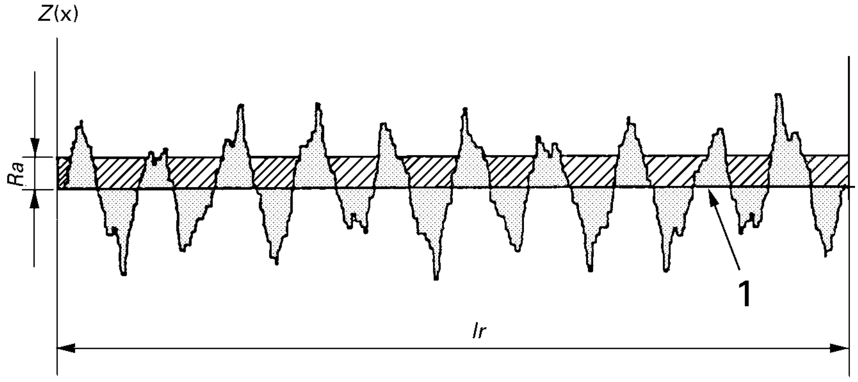
$$Ra = \frac{1}{lr}\int_0^{lr}\left|z(x)\right|\,dx \qquad (1)$$

where

lr is the sampling length for *Ra*;

$Z(x)$, Z_i are the ordinate values.

NOTE The arithmetical mean deviation, *Ra*, is determined by an evaluation length of five adjacent sampling lengths (see Figure 4 and ISO 4288).



Key
1 Mean line

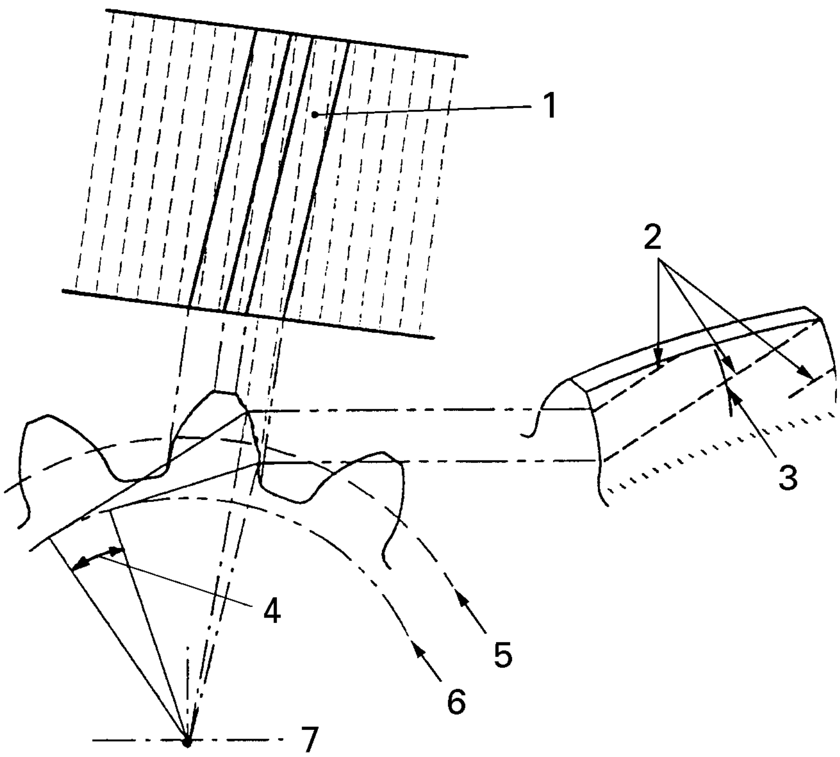
Figure 4 — Arithmetic mean deviation of the roughness profile, *Ra*

3.2.4
gear tooth undulations
Undulations are periodic waviness in a tooth surface. A special form of undulations meets the following criteria:

— the lay is approximately parallel to the lines of contact (with the mating gear);

— the number of waves projected on a pitch circle (in a plane of rotation) is an integer, see Figure 5;

— they are a likely cause of noise.



Key
1 Projections on pitch cylinder
2 Crests of undulations (with lay approximately parallel to lines of contact)
3 Path of contact
4 Angle of roll between undulations
5 Pitch circle
6 Base circle
7 Section in plane of rotation

Figure 5 — Undulations in a helical gear

4 Surface texture

Experimental investigations and service experience indicate that a relationship exists between grades of surface texture and aspects of gear load capacity. The influence of surface roughness on the pitting resistance and bending strength of gear teeth is addressed in ISO 6336, Parts 2 and 3 respectively; its influence on scuffing is discussed in ISO/TR 13989.

As well as roughness, waviness and other features of surface texture can influence the surface fatigue resistance of materials. Because of this, it is prudent to make an unfiltered profile recording of the surface texture of the teeth of gears when high standards of performance and reliability are demanded.

In this Technical Report no recommendations are made concerning the grades of surface roughness, waviness and form or type of lay suitable for specific purposes, nor are causes of such irregularities identified.

CAUTION It is strongly recommended that before prescribing limits for features of the surface texture of gear teeth, designers of gears and gear engineers should familiarize themselves with ISO standards and other literature on the subject. See references in clause 2.

5 Functional considerations

The functional characteristics of gear teeth that are affected by surface texture can be separated into categories:

- transmission accuracy (noise and vibration);
- surface load carrying ability (such as pitting, scuffing, and wear);
- bending strength (root fillet condition).

5.1 Transmission accuracy

Surface texture can be described as having two major forms: roughness and waviness.

Transmission errors can be caused by surface waviness or undulations in the tooth surface. The effect depends on the direction of the lay of the waves relative to the instantaneous line of contact and its path. If the lay of the waves is parallel to the instantaneous line or area of contact (perpendicular to the path of contact), a high pitched whine can occur in the gear mesh (ghost harmonics above mesh frequency).

In a few cases, surface roughness can make a difference in the character of gear noise (smooth vs. rough quality). It does not normally contribute to the noise occurring at gear mesh frequency and its harmonics.

5.2 Load carrying ability

Surface texture can affect the gear tooth endurance in two general areas: surface deterioration and tooth breakage.

5.2.1 Surface deterioration

Surface deterioration is described in terms of wear, scuffing or scoring, pitting, etc. Surface roughness and waviness on the tooth profile is of concern. The surface texture, temperature and lubricant determine the elasto-hydrodynamic (EHD) film thickness, which affects the endurance of the tooth surface.

5.2.2 Bending strength

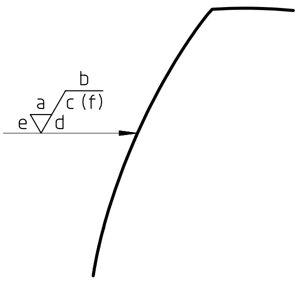
Tooth breakage can be the result of fatigue (high cyclic stress). Surface texture effect on stress in the fillet region is of concern as an influential factor.

5.3 Effect on measurement method

The measurement method instrumentation, location, direction, and analysis (filter, etc.) must be chosen to represent the functional area of the tooth and the path of contact.

6 Data given in drawings

When specified by the customer, or when design and operational requirements make it necessary, an appropriate value of surface roughness for the finished condition is to be stated in the drawing as shown in Figures 6a and 6b.



a = *Ra* or *Rz*, µm

b = production process, surface treatment etc.

c = sampling length

d = direction of lay

e = machining allowance

f = other roughness values (in brackets)

Figure 6a — Symbols for surface texture

Key

1 Tooth flank excluding fillet

2 Tooth flank including fillet

Figure 6b — Symbols for roughness and direction of lay

7 Measuring instruments

Stylus type measuring instruments are commonly used for the measurement of roughness. The measurement can be taken with the following equipment, that includes characteristics that influence the uncertainty of measurement (see Figure 7):

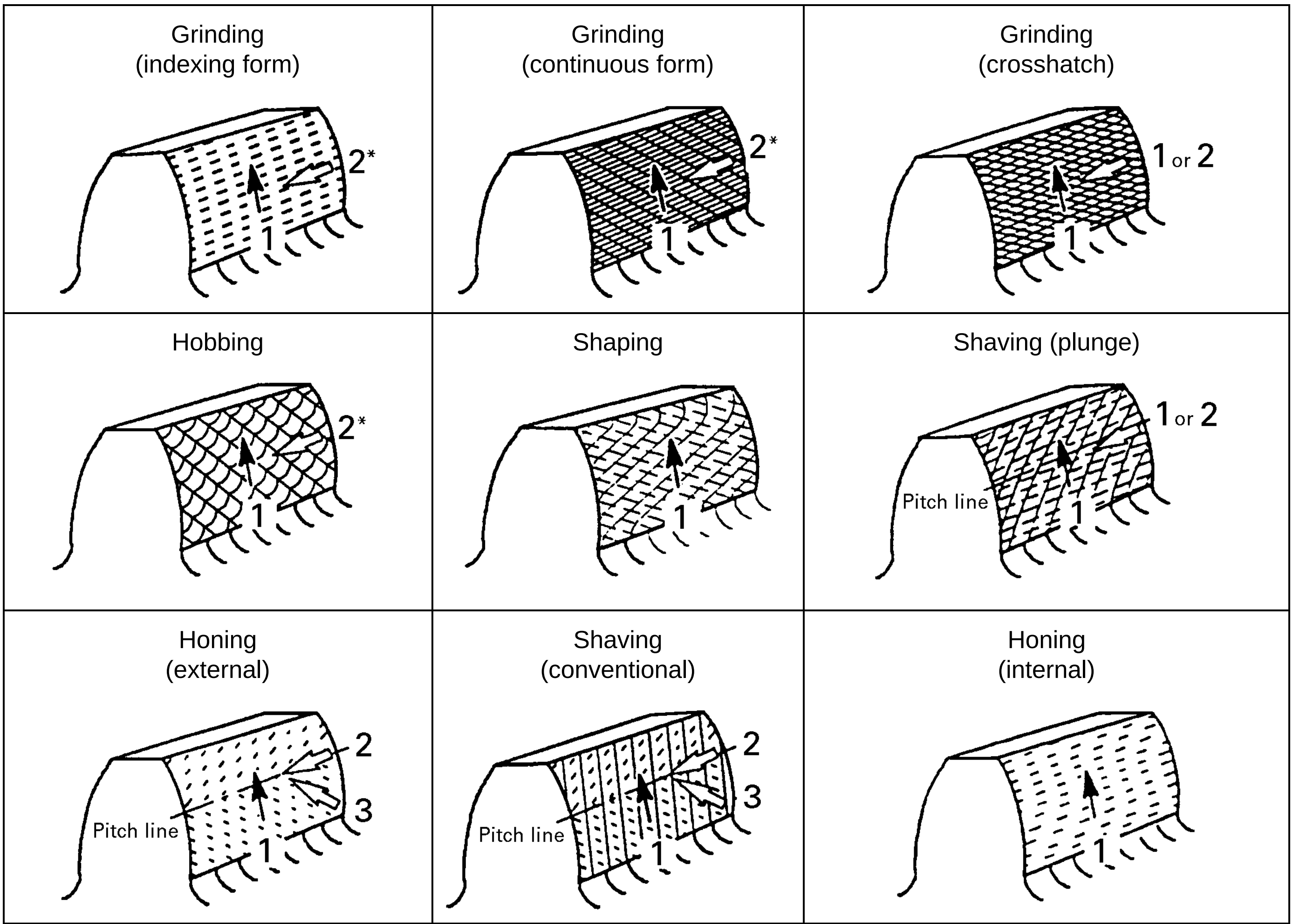
a) one skid or by a pair of skids which slide over the surface to be measured (instrument with a straight reference plane);

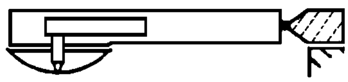
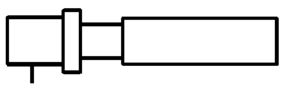
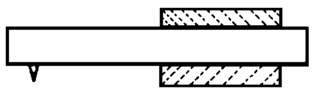
b) a skid which slides over a reference plane having the form of the nominal surface;

c) an adjustable or programmable reference line generator in combination with a skid, e. g. realized by a coordinate measuring machine;

d) assessment of form, waviness and roughness by a skidless pickup and straight datum combined with a large measuring range.

To comply with ISO standards, the tip radius of the stylus is to be 2 µm, or 5 µm, or 10 µm. The stylus angle may be 60° or 90°. Further details of instrument features can be found in ISO 3274. The report of the surface measurement should indicate tip radius and angle of stylus.



Direction of traverse	Instrument type		
1 and 3	Instrument with a skid	Side mounted skid	
2		Front mounted skid	
2*	Instrument with reference guide		

↑ preferred direction of measuring traverse for the determination of: *Rz, Ra, Rk*

⇦ direction of measurement traverse for the determination of additional information such as the height of small feed marks

Figure 7 — Instrument features and directions of measurement traverse relative to manufacturing

For the measurement of roughness or waviness it is necessary to use a skidless pickup and a filter with a defined cut-off, which will suppress the long wave components or the short wave components of the surface profile. Instruments are available with only certain specific cutoffs. Refer to Table 2 for appropriate cutoff wavelengths. Care must be taken to select the appropriate stylus tip radius, sampling length and cut off filter; see ISO 3274, ISO 4288 and ISO 11562, otherwise a systematic error of measurement may occur.

Functional considerations of the effects of waviness, direction of lay and measuring instruments may require the choice of a different cutoff value.

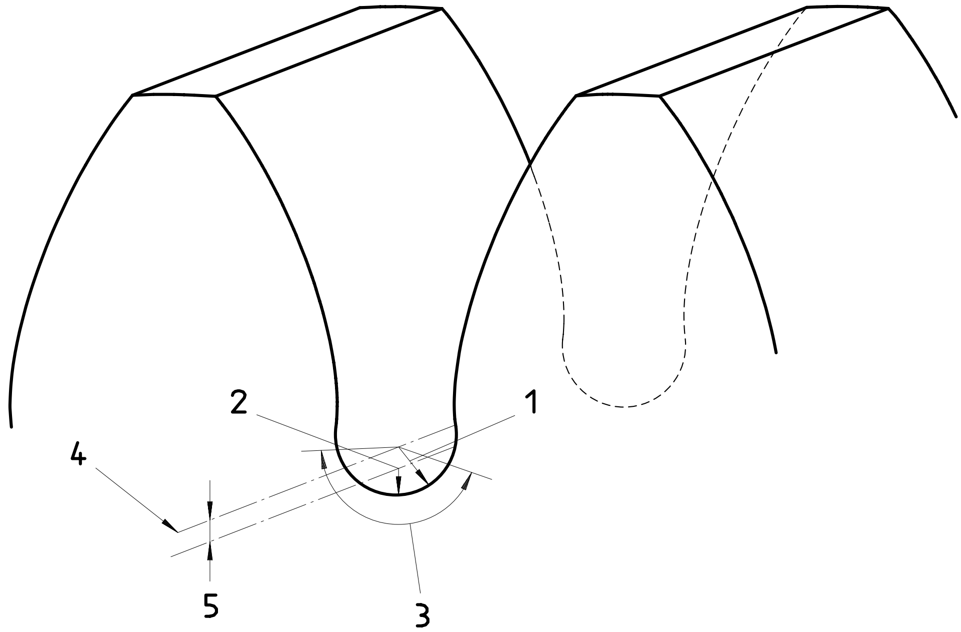
Table 2 —Filtering and cutoff wavelengths

Module mm	**Standard working tooth depth** mm	**Standard cutoff** mm	**Cutoffs in working tooth depth**
1,5	3,0	0,2500	12
2,0	4,0	0,2500	16
2,5	5,0	0,2500	20
3,0	6,0	0,2500	24
4,0	8,0	0,8000	10
5,0	10,0	0,8000	12
6,0	12,0	0,8000	15
7,0	14,0	0,8000	17
8,0	16,0	0,8000	20
9.0	18,0	0,8000	22
10,0	20,0	0,8000	25
11,0	22,0	0,8000	27
12,0	24,0	0,8000	30
16,0	32,0	2,5000	13
20,0	40,0	2,5000	16
25,0	50,0	2,5000	20
50,0	100,0	8,0000	12

8 Measurement of the surface roughness of gear tooth flanks

This clause describes the preferred values of parameters, the cut off and evaluation length, and the procedures for the measurement of the tooth and root fillet surface textures of cylindrical involute gears.

When measuring surface roughness, the path of the stylus should be perpendicular to the direction of the lay of the surface. See the directions indicated in Figures 7 and 8. The measurement should also be perpendicular to the surface. Therefore, the curvature of the tooth surface shall be followed as close as possible by the stylus.



Key

1 Fillet radius

2 Skid radius

3 Arc of measurement

4 Rotation axis

5 Offset of stylus axis

Figure 8 — Measurement of root fillet roughness

When the roughness of the fillet surface at the root of a gear tooth is measured, one direction is to be at right angles to the helix, and for this, special methods may be required. One suitable arrangement is shown in Figure 8 wherein the sensing head, with a skid radius, *r*, smaller than the fillet radius, *R*, in front of the stylus, is so mounted on a rotatable spindle that when turning the spindle through an angle of about 100°, the stylus tip describes a circular arc approximation of the tooth root fillet. When fillets are sufficiently large and with careful positioning of such a device, roughness measurements can be made.

NOTE The skid radius, *r*, used directly on a surface should be such that $r > (50\ \lambda c)$ to avoid measuring uncertainty due to skid.

Alternatively, an inverted replica can be prepared, using a suitable casting material (resin etc.), for measurement using a skid type measuring instrument. This method is especially useful when the roughness of the tooth root fillets of fine pitch gears is to be measured. When this method is used, it is important to bear in mind during the evaluation that profile recordings are inverted.

8.1 Evaluating measurements results

Directly measured roughness parameters can be compared directly with specified allowable values.

A parameter value is usually determined as the mean of several values from a number of contiguous sampling lengths taken along the profile. But it should be taken into account that surface roughness can change systematically along the course of the gear flank. Therefore it can be advantageous to determine the roughness values for the single contiguous sampling lengths. To improve the statistical certainty of the values, arithmetic mean values can be calculated from several parallel traces.

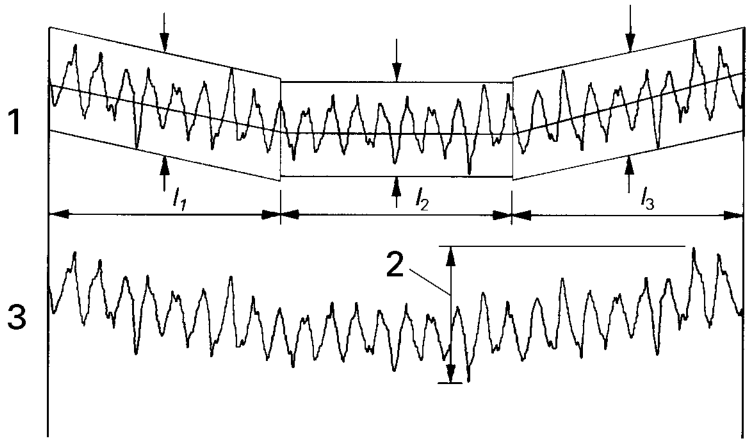
Best results can be expected if the profile is measured without a skid relative to a reference. This is the case with the equipment mentioned under point b and point d in clause 7.

Referring to clause 7, roughness, waviness, form and form deviations are assessed simultaneously.

To separate, in this case, roughness from the longer wave content of the profile, first the nominal form component has to be eliminated before filtering with a phase correct filter according to ISO 11562 and ISO 4288.

When gear tooth profiles are too small to make a measurement on five adjacent sampling lengths, measurement over single sampling lengths on separate teeth is permitted (see ISO 4288:1996, clause 7).

To prevent a loss of a part of the evaluation length by using a filter, it is possible to evaluate roughness over single sampling lengths without the standardized filtering procedure. Figure 9 explains the filtering effect for suppressing form, etc., by subdividing the traced profile (without filter) in short sampling lengths, l_1, l_2, l_3, etc. For comparable results to the standardized method with filter, the sampling lengths should be of the same value as the cut-off value, λc.



Key

1 Filtered with straight line mean

2 Amplitude

3 Unfiltered

Figure 9 — Influence of the sampling length and filtering

8.2 Parameter values

Values derived from parameters are to be compared with specified values. Specified parameter values should preferably be chosen from the ranges shown in Tables 3 and 4. Either *Ra* or *Rz* may be used as a criteria, but both should not be used on the same part.

There is no direct relation between the gear accuracy grades according to ISO 1328-1 and the roughness classes of Tables 3 and 4.

NOTE The equivalent surface condition classes in these Tables for *Ra* and *Rz* do not correspond to specific manufacturing practices. This particularly applies for the values listed in classes 1 through 4.

Table 3 — Recommended limit values for arithmetic mean deviation, *Ra*, in µm

Class	*Ra*		
	Module in mm		
	$m < 6$	$6 \leqslant m \leqslant 25$	$m > 25$
1		0,04	
2		0,08	
3		0,16	
4		0,32	
5	0,5	0,63	0,80
6	0,8	1,00	1,25
7	1,25	1,6	2,0
8	2,0	2,5	3,2
9	3,2	4,0	5,0
10	5,0	6,3	8,0
11	10,0	12,5	16
12	20	25	32

Table 4 — Recommended limit values for ten point height irregularities, *Rz*, in µm

Class	*Rz*		
	Module in mm		
	$m < 6$	$6 \leqslant m \leqslant 25$	$m > 25$
1		0,25	
2		0,50	
3		1,0	
4		2,0	
5	3,2	4,0	5,0
6	5,0	6,3	8,0
7	8,0	10,0	12,5
8	12,5	16	20
9	20	25	32
10	32	40	50
11	63	80	100
12	125	160	200

8.3 The Abbott Firestone curve (material ratio curve) of roughness profile

Parameters describing the functional characteristics of surface roughness which are relevant to highly stressed contact surfaces are defined by the material ratio curve (see ISO 4287).

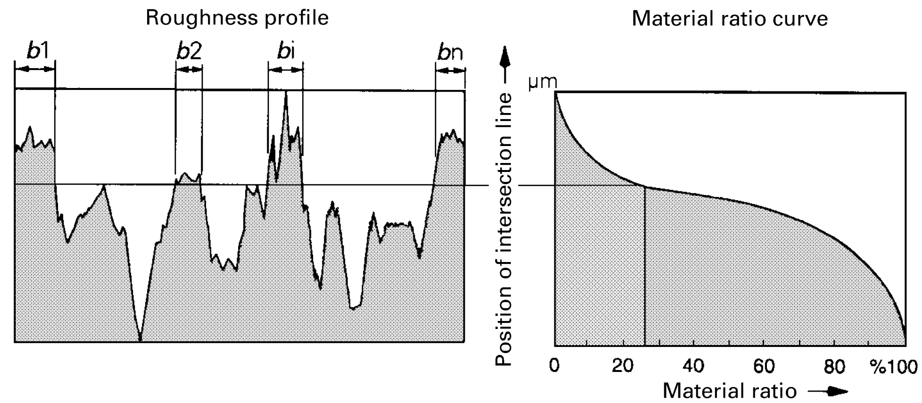
For highly stressed contact surfaces it is also essential that prescribed limits of shape and waviness deviations be kept to very small values.

The parameters characterize the shape of the material ratio curve and thereby the height and nature of the roughness profile. A fully representative, error free, filtered roughness profile is a prerequisite for the surface texture assessment process described in the following paragraphs.

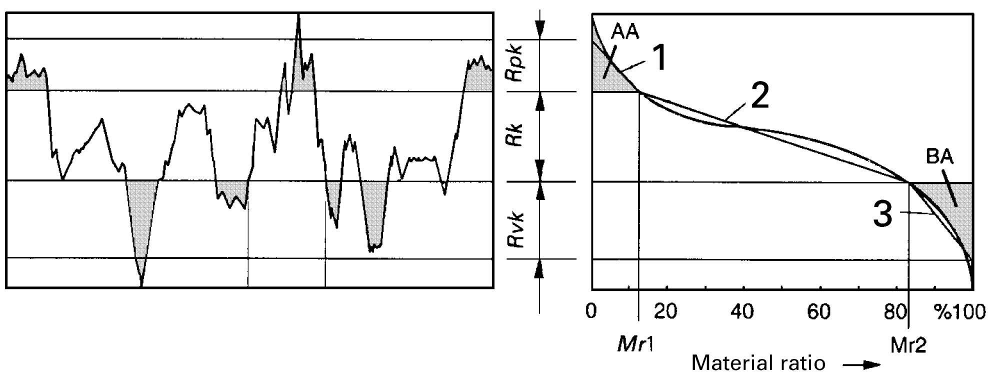
8.3.1 Terms associated with material ratio curve

a) **Intersection line:** A line parallel to the mean line which cuts the roughness profile. See Figure 10a;

b) **Material length:** The sum of those section lengths of the intersection line which lie within the profile peaks, expressed as a percentage of the evaluation length (see ISO 4287:1997, 3.2.14 for material length of profile at level, *c*).



a) Relationships between roughness profile and material ratio curve



b) Approximation of material ratio curve by 3 straight lines

Figure 10 — Characteristic values of the material ratio curve according to ISO 13565-2

8.3.2 Structure of the material ratio curve

Coordinates of each point on the material ratio curve of roughness profile are:

a) **On the x axis:** The material lengths of five contiguous sampling lengths, expressed as a percentage of the evaluation length;

b) **On the z axis:** The ordinate to the line intersecting the roughness profile. See Figure 10a.

8.3.3 Parameters of the material ratio curve

a) **Roughness core profile:** The roughness core profile is the roughness profile excluding the protruding peaks and deep valleys; see ISO 13565-2:1996, 3.1.

b) **Core roughness depth, *R*k, in µm:** The core roughness depth is the depth of the roughness core profile (figure 10b); see ISO 13565-2:1996, 3.1.1.

c) **Material portion, *Mr*1, in %:** The material portion, *Mr*1, is determined for the intersection line which separates the protruding peaks from the roughness core profile; see ISO 13565-2:1996, 3.1.2.

d) **Material position, *Mr*2, in %:** The material portion, *Mr*2, is determined for the intersection line which separates the deep valleys from the roughness core profile; see ISO 13565-2:1996, 3.1.3.

e) **Reduced peak height, *Rpk*, in µm:** The reduced peak height, *Rpk*, is the averaged height of the protruding peaks above the roughness core profile; see ISO 13565-2:1996, 3.2.

f) **Reduced valley depth, *Rvk*, in µm:** The reduced valley depth, *Rvk*, is the averaged depth of the profile valleys projecting through the roughness core profile; see ISO 13565-2:1996, 3.3.

NOTE The averaging process in 8.3.5 reduces the effect of outlier values on *Rpk* and *Rvk*.

8.3.4 Material ratio curve measurement conditions

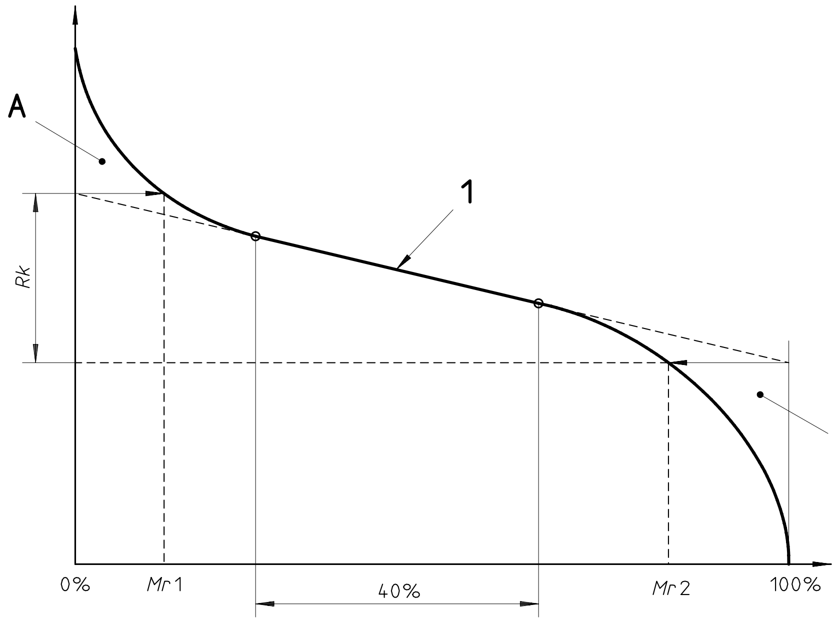
a) **Material ratio curve measurement instrumentation:** It is recommended that measurements intended for determination of material ratio curve parameters be executed using stylus instruments with geometrical surface or reference line generator control of the stylus path.

b) **Measurement direction:** The measurement path which gives the largest value of roughness is to be chosen.

8.3.5 Determination of the parameters of the material ratio curve

8.3.5.1 Determination of *Rk, Mr*1, *Mr*2

In a section between abscissa *Mr*1 and *Mr*2, 40% apart, draw through the material ratio curve the mean straight line having the smallest gradient relative to the x-axis, see Figure 11. If there are two or more such sections with equal gradient, the one nearer the higher end of the curve is determinant. The difference between the ordinates to this line at 0% and 100% is equal to *Rk*.



Key

1 Mean straight line

Figure 11 — Determination and measurement of the characteristic values *R*k, *Mr*1 and *Mr*2

8.3.5.2 Determination of *Rpk* and *Rvk*

Draw intersecting lines A and B from the intercepts and on the y-axis at 0% and 100% to cut the roughness profile. See Figures 11 and 12. Determine the total area AA of the roughness profile above line A and the total area BA of the valley profile below line B.

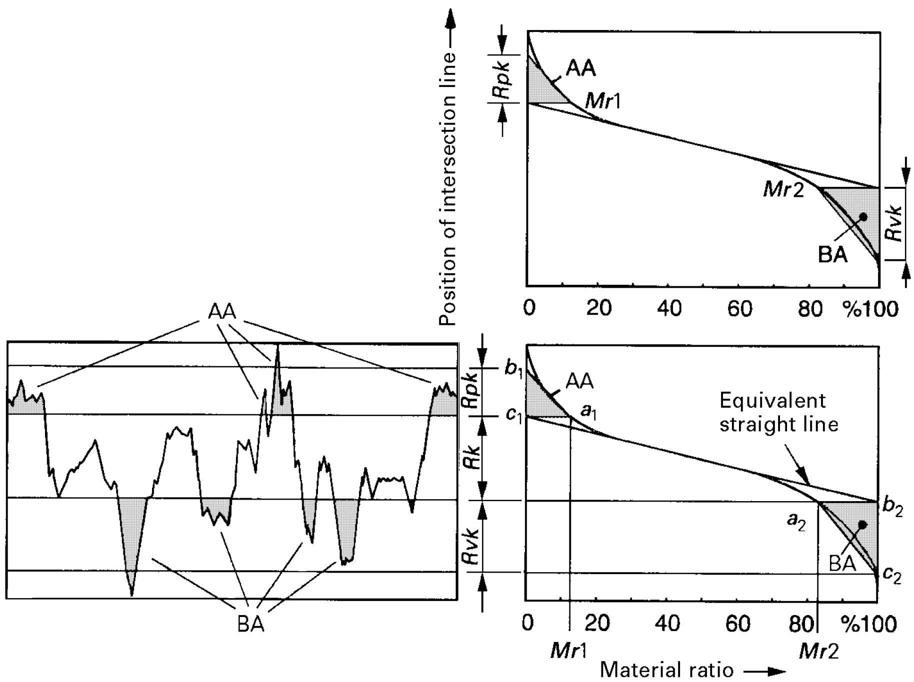


Figure 12 — Determination of *Rpk* and *Rvk*

On the z-axis at 0% on the line segment c_1 - a_1 construct a right triangle a_1, b_1, c_1 with area equal to AA.

On a parallel to the z-axis at 100% on the line segment c_2 - a_2 construct a right triangle a_2, b_2, c_2 with area equal to BA.

The side c_1- b_1 is equal to *Rpk*, the side c_2 - b_2 is equal to *Rvk*.

Comparison of material ratio curves for different roughness profiles gives some indication as to how these curves might be used in the estimation of relative resistance of a given surface to surface damage.

8.3.6 The use of material ratio curve parameters *Rk*, *Rpk*, *Rvk*

Figure 11 clarifies that the meaning of *Rk* cannot only be expressed by a profile depth value, but also by a slope value of the dominant part of the material ratio curve.

The slope of the material ratio curve is most important. Its value indicates the increase of the material ratio by penetrating deeper into the core profile. Therefore *Rk* is significant for the load capacity of the surface.

ISO 13565-2 parameters describe the shape of the material ratio curve by means of 3 straight lines, which subdivide the total profile depth in:

— the peak area (related to initial operating behaviour, such as running in and wear);

— the core area (related to load capacity, functional performance, etc.);

— the valley area (related to lubrication, oil retention, etc.).

Figure 13 illustrates the separation procedure of protruding peaks and valleys from the core profile. It shows clearly a distinct separation of peaks and valleys, if *Rk* is equal to zero (see Figure 13a). Figure 13b shows the development of an *Rk* value (realized by the straight line in the middle) which is excluding extreme protruding peaks and valleys on a surface with nearly Gaussian distributed ordinates.

Although the metrological determination has been no more difficult than the determination of *Ra* or *Rz*[1)] for gears, the information afforded by the parameters of the material ratio curve is not yet sufficiently developed for current use. As a result, recommended values cannot at present be given for those parameters.

[1)] Beyer, Eckolt, Hillmann, Wittekopf, *Investigation of gear tooth flanks using scanning electron microscopy and stylus type surface measuring instruments.* PTB report PTB-F-2 (November 1987).

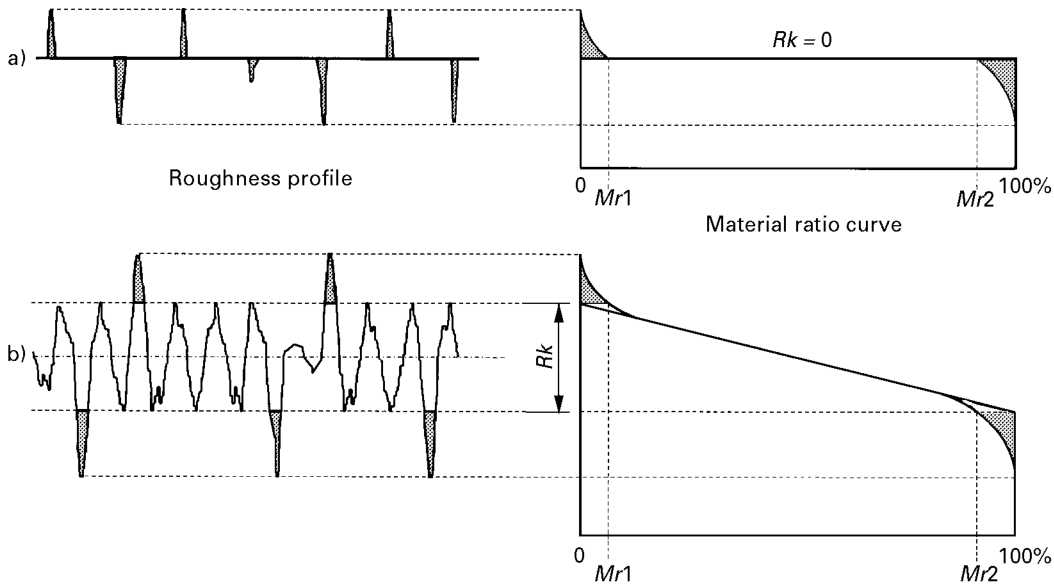


Figure 13 — Influence and properties of the roughness core area on the determination of the amount of protruding peaks and valleys

9 Inspection of tooth contact pattern

In this clause, methods of obtaining, and analyzing contact patterns are explained. Also guidance on estimating gear accuracy is given.

Patterns of contact generated between product gear pairs in their gear cases helps in the assessment of the load distribution between teeth.

Patterns of contact between product gears and master gears can be used for assessment of helix and profile accuracy of assembled gears.

9.1 Test conditions

9.1.1 Accuracy

Light-load contact patterns between product and master gears can be obtained with the gears mounted in a meshing frame. For this, it is essential that misalignment of the gear axes over a length equal to the product gear facewidth should, as nearly as can be determined, not exceed 0,005 mm. It is also necessary that the facewidth of the master gear is not less than that of the product gear. Usually this means that for helical gears, a special master is required. For large gears, such a master can be a specially made sample of a product gear which is retained to facilitate production of replacements for gears which may have been damaged.

The contact patterns of matched pairs of product gears may also be obtained in a meshing frame.

9.1.2 Load distribution

Light-load contact patterns between product gear pairs in their gear cases is an aid to the assessment of probable distribution of load. When generating these, the journals of the gears should be in their working attitudes. This can be accomplished by shimming the bearing journals.

9.1.3 Marking compound

Suitable marking compounds include: Toolmaker's blue marking compound and other proprietary compounds. A method of application should be chosen which will ensure that the thickness of an applied film will be between 0,006 mm and 0,012 mm.

9.1.4 Calibration

Calibration of the thickness of the marking compound is essential to interpretation of contact pattern test results. Once an operator has developed a consistent technique, it is possible to establish the thickness of the marking compound by shifting the axes of the gears out of parallel in a vertical direction in the tangential plane by a known angle; i.e., shimming one bearing support and observing the change in the pattern. This calibration should be performed regularly to be sure that the marking compound, test load, and operator technique have not varied.

9.1.5 Test load

The load used in generating a light load contact pattern should be just enough to ensure that the flanks being inspected remain firmly in contact.

9.1.6 Recording results

Contact patterns are usually recorded as sketches, as photographs, as video records or by covering the pattern with transparent adhesive tape which is then peeled off with the adhering contact pattern compound, then mounted on good quality white card.

9.2 Operator training

Personnel required to perform the above operations should be trained to do so correctly and their results should be checked periodically to ensure consistency of performance.

9.3 Interpretation of patterns

Contact patterns can give an indication of the extent of alignment inaccuracies including misalignment and waviness; also of profile inaccuracies. It must be emphasized that any conclusions drawn are subjective, are only approximate and depend on the expertise of the personnel involved.

9.3.1 Patterns with master gears

Figures 14 through 17 show sketches of typical contact patterns generated by product gears with master gears.

9.3.2 Gear accuracy and patterns

Figure 18, with Tables 5 and 6, give a general indication of the expected relationship between gear accuracy grades and contact pattern distributions when gears are checked after assembly (unloaded). It must be borne in mind that the actual patterns do not necessarily have the same form as that shown in Figure 18. Results obtained for gears checked in a meshing frame should be similar.

NOTE Figure 18, Table 5 and Table 6 are not applicable for tooth flanks with profile and longitudinal modifications.

CAUTION: These tables are intended to indicate the best pattern that can be obtained for gears that have been demonstrated by direct measurement to be of the tabulated accuracy. They must *not* be interpreted as being an alternative method of proving gear accuracy grade.

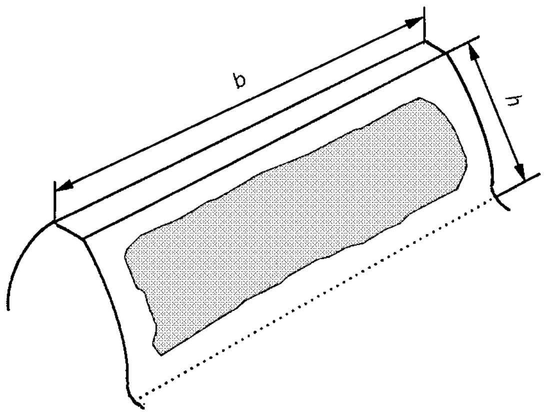


Figure 14 — Typical specification, contact approximately *b* = 80% *h* = 70%, tooth ends relieved

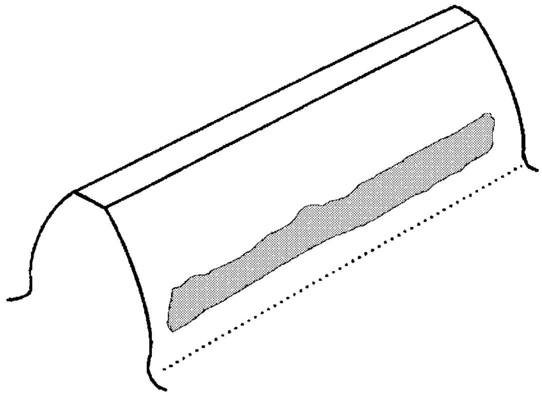


Figure 15 — Correct alignment, with profile deviation

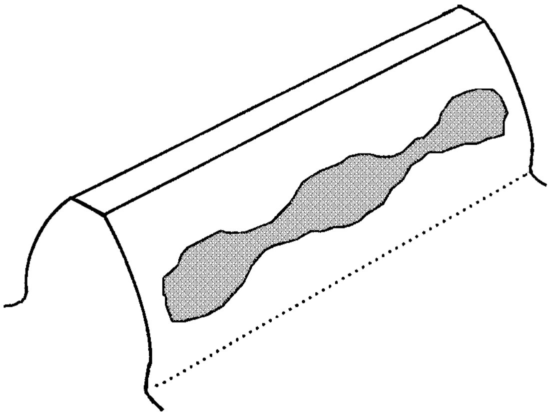


Figure 16 — Waviness

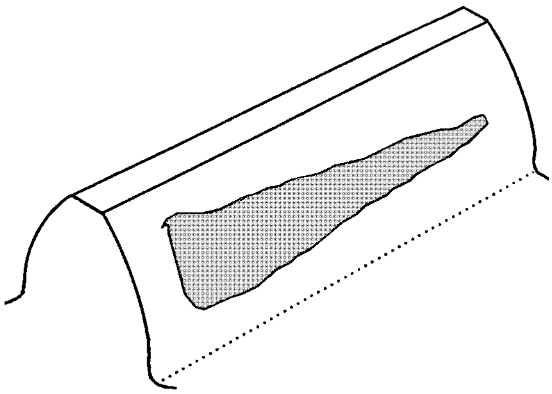


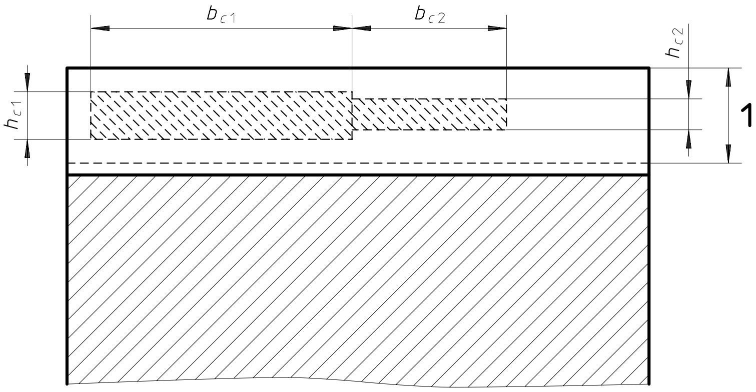
Figure 17 — Helix deviation, profile correct, with tooth ends relieved

Table 5 — Contact pattern on assembly for helical gearing

Accuracy grade (ISO 1328)	b_{c1} % facewidth	h_{c1} % active flank height	b_{c2} % facewidth	h_{c2} % active flank height
4 and finer	50%	50%	40%	30%
5 and 6	45%	40%	35%	20%
7 and 8	35%	40%	35%	20%
9 to 12	25%	40%	25%	20%

Table 6 — Contact pattern on assembly for spur gearing

Accuracy grade (ISO 1328)	b_{c1} % facewidth	h_{c1} % active flank height	b_{c2} % facewidth	h_{c2} % active flank height
4 and finer	50%	70%	40%	50%
5 and 6	45%	50%	35%	30%
7 and 8	35%	50%	35%	30%
9 to 12	25%	50%	25%	30%



Key

1 Height of active flank

Figure 18 — Schematic distribution of contact pattern

Annex A

Controlling gear tooth alignment with contact patterns

A.1 Purpose

This annex describes the use of contact patterns to specify and control the alignment of gear teeth.

Two methods of developing a contact pattern are discussed:

— static method, by the transfer of soft coatings;

— dynamic method, by the wear of a hard coating.

A.2 Application

A.2.1 Typical usage

Contact patterns are used as a quantitative and qualitative measure of the alignment of gear teeth. They are most often used on large parts which will not fit into available inspection machines, and on site where no inspection machines are available. The advantages of this method are:

— portability of the test equipment;

— ability to test large or complex surfaces which can't be tested by other means;

— speed and ease of use;

— reproducibility of test results, if proper calibration methods are used;

— sensitivity to actual mounting conditions, such as bearing misalignment and gear case distortion;

— ability to detect small alignment errors and system errors, such as undulation, which are not apparent in lead and profile charts;

— ability to evaluate tooth conformity, including the effects of additive or cumulative deviations in wheel and pinion, which are not apparent in lead and profile charts;

— ability to evaluate the whole tooth surface, rather than a single line representing profile or tooth alignment.

A.2.2 Specific fields of use

Some specific examples where contact pattern test methods are used:

— large marine gears;

— high speed gears;

— field assembly of marine and high speed gear units;

— assembly of exposed final drive gears in cranes, hoists, bridges, microwave antennas etc.;

— bevel gears;

— aerospace gears.

A.2.3 Methods

The static method, accomplished by the transfer of a light coating between pinion and wheel, is done without load, normally turning by hand.

The dynamic method requires controlled increments of measurable load and should normally be accomplished at design operating speeds.

A.3 Description

A.3.1 Static method

Contact pattern checking transfers marking compound of a prescribed thickness from the teeth on one gear to the teeth on a mating gear. The resulting “contact pattern” is compared to a specified pattern, developed from analysis of the desired no load contact conditions or from experience with similar gear pairs. The technique is similar to that used when hand fitting or "scraping in" the contact surfaces of precision instruments and precision machine tools.

A.3.2 Dynamic method

Contact patterns, which are displayed by the removal of a coating in the loaded contact area between mating teeth, during short runs at increments of load are observed and recorded. Typical load increments are 5%, 25%, 50%, 75% and 100%. The resulting “contact patterns” are compared to assure that the areas develop progressively across the teeth such that the designed amount of contact is observed under normal operating conditions.

A.4 Equipment and materials

a) Cleaning solvent

b) Marking compounds

- red lead;
- proprietary compounds;
- mixtures of ground pigments with oil;
- paste Prussian blue;
- dye penetrant developer, a white powder packaged as an aerosol spray, sold as part of dye penetrant crack detection kits;
- layout ink.

c) Recording means

- photography;
- transparent tape and white paper as big as the teeth;
- sketches.

d) Measuring instruments for calibration

- precision shims or feeler gauges;
- dial indicators.

A.5 Static method

A.5.1 Testing

A.5.1.1 Alignment of axes

When the gear case is not available or the gears are to be tested in the shop for later mounting in the field, shop tests are performed using test stands and rolling fixtures to position the gears in their correct relative positions. It is essential that the gear axes be exactly parallel and co-planar. An error of as little as 0,000 10 radian in the alignment of the axes will adversely affect the reproducibility of the results. In a typical procedure, a precision straight edge is placed across the gear shafts with precision gauge blocks between the smaller diameter shaft and the straight edge to compensate for the difference in shaft radius. A precision spirit level is placed on the top of the straight edge and the height of one of the shafts is adjusted until the straight edge is level. This procedure is repeated at the center of each pair of bearing journals. The center distance and parallelism are checked by precision measurement between the shafts which support the test gears. Rolling fixtures (meshing frames) with easily adjustable bearing supports are often found in shops where contact checking is done.

If the contact test is to be performed in an unmounted gear case, it is essential that the case be leveled as accurately as possible to avoid misalignment of the gear axes. Misalignment of the axes will affect the contact pattern results to the same extent as in a rolling fixture.

If the contact test is repeated after the gear case is mounted, the changes in contact pattern from the unmounted, leveled contact pattern will reveal any distortion of the gear axes due to distortion of the case during installation.

A.5.1.2 Procedure

The teeth to be tested should be thoroughly cleaned with solvent to remove any contamination or oily residue. Three or more teeth of the pinion are then painted with a thin layer of the marking compound, using a stiff bristle brush. A suitable brush can be made by trimming the bristles of an ordinary 25 mm wide paint brush to a length of about 10 mm. The resulting film should be smooth and thin. It is not necessary to remove all brush marks, since they will smear together during the test. The film should be between 5 and 15 µm thick (see calibration, A.5.2).

After the pinion teeth are painted they should be covered to protect them from over spray and a very thin film of the developer sprayed onto the gear teeth which will be in mesh with the painted pinion teeth. This spray is intended to hide the gloss on the gear teeth and to make the contact pattern easy to read, not to build up a significant film thickness.

After the teeth are painted, the operator rolls the painted pinion teeth through mesh with the wheel, with an assistant providing enough back torque on the wheel to assure contact. The parts are then rolled back to their original position to mark the back side of the teeth and to bring the contact patterns into view. The procedure is repeated in at least three equally spaced locations on the wheel to reveal any variation in the contact pattern due to wobble or other periodic errors.

A.5.1.3 Recording results

The resulting contact patterns should be recorded by photography, sketches or tapes. Instant development photography and tapes are the most common methods. Tapes are made by carefully pressing strips of transparent mending tape over the contact pattern then carefully removing the tape and sticking it on white paper. The contact pattern is preserved between the tape and paper. It can be reproduced by black and white or color electrostatic copiers. It is essential to label the tape patterns to indicate which tooth was used and to orient the pattern with respect to flank, tip and root.

Contact pattern tapes can be furnished with replacement gear sets intended for field assembly, to be compared with contact patterns made in the field after assembly and to verify proper assembly.

A.5.2 Calibration

In order for the results to be meaningful and reproducible, the thickness of the marking compound combination must be controlled and consistent.

The thickness of the marking compound is easily measured by either of the following techniques.

A.5.2.1 As part of a contact test, deliberately raise one bearing on the pinion shaft by an amount sufficient to slope the pinion axis 0,000 10 radian. Record the pattern and repeat the test, on the same tooth, with the bearing in its normal (leveled) position. The thickness of the compound is established from the amount of shift in the contact pattern and the geometry of the angle. For example, if the length of the contact pattern is 50 mm with the axes misaligned 0,000 10 radian and changes to 100 mm when the axes are parallel, the compound thickness is 0,010 mm.

A.5.2.2 A similar verification of the operator's technique can be done with a surface plate and precision straight edge by painting the edge of the straight edge with marking compound and lowering one end of the straight edge onto a surface plate and the other end onto a shim of known thickness which rests on the surface plate. The compound thickness is equal to the thickness of the shim multiplied by the ratio of the length of the contact pattern to the length of the straight edge.

A.5.2.3 Calibration tests should be performed and documented as part of the record of the inspection. The thickness of the marking compound depends on the skill and technique of the operator. If qualified operators who are regularly performing contact tests are used, it isn't necessary to recalibrate their technique for each test. The thickness of the compound can be established at any time, for critical tests or audit, by using the calibration methods above and recording the results.

A.6 Dynamic Method

A.6.1 Procedure

The teeth to be tested should be thoroughly cleaned with solvent to remove any contamination or oily residue, before each run. Three or more teeth of both pinion and wheel are then sprayed with a thin coat of layout ink. The resulting film should be smooth and thin. Care should be taken not to build up a significant film thickness. Therefore, after each run, the teeth should be thoroughly cleaned with solvent to remove any remaining ink, contamination, or oil.

After the teeth are coated, the gears are operated at an increment of load for a short period, stopped and contact pattern recorded. The teeth are then thoroughly cleaned and the process repeated at the next load increment. The procedure is repeated for at least three different loads.

A.6.2 Recording results

The resulting contact patterns should be recorded by photography or sketches.

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[2)] To be published.

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Descriptors: gears, cylindrical gears, teeth (mechanics), inspection, inspection by measurements, texture, roughness, roughness measurement, dimensional deviations, codes of good practice.

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