INTERNATIONAL STANDARD

ISO 1328-1

Second edition
2013-09-01

Cylindrical gears — ISO system of flank tolerance classification —

Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth

Engrenages cylindriques — Système ISO de classification des tolérances sur flancs —

Partie 1: Définitions et valeurs admissibles des écarts pour les flancs de la denture

Reference number
ISO 1328-1:2013(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 1328-1 was prepared by Technical Committee ISO/TC 60, *Gears*.

This second edition cancels and replaces the first edition (ISO 1328-1:1995), which has been technically revised. In particular, the following are the major changes:

— the scope of applicability has been expanded;

— revisions have been made to the formulae which define the flank tolerances;

— annexes have been added to describe additional methods for analysis of modified profiles and helices;

— the evaluation of runout, previously handled in ISO 1328-2, has been brought back into this part of ISO 1328.

ISO 1328 consists of the following parts, under the general title *Cylindrical gears — ISO system of flank tolerance classification*:

— *Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth*

— *Part 2: Definitions and allowable values of deviations relevant to radial composite deviations and runout information*[1)]

1) It is intended that, upon revision, the main element of the title of Part 2 will be aligned with the main element of the title of Part 1.

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Introduction

ISO 1328:1975 (third edition, withdrawn) included definitions and allowable values of gear element deviations, along with advice on appropriate inspection methods.

The first edition of this part of ISO 1328 retained the definitions and allowable values for gear flank deviations (single pitch, cumulative pitch, total cumulative pitch, total profile and total helix), while the advice on appropriate inspection methods was given in ISO/TR 10064-1 (listed in Clause 2).

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Cylindrical gears — ISO system of flank tolerance classification —

Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth

IMPORTANT — It is strongly recommended that any user of this part of ISO 1328 be very familiar with the methods and procedures outlined in ISO/TR 10064-1. Use of techniques other than those of ISO/TR 10064-1 combined with the limits described in this part of ISO 1328 might not be suitable.

CAUTION — The use of the flank tolerance classes for the determination of gear performance requires extensive experience with specific applications. Users of this part of ISO 1328 are cautioned against the direct application of tolerance values for unassembled (loose) gears to a projected performance of an assembly using these gears.

1 Scope

This part of ISO 1328 establishes a tolerance classification system relevant to manufacturing and conformity assessment of tooth flanks of individual cylindrical involute gears. It specifies definitions for gear flank tolerance terms, the structure of the flank tolerance class system, and allowable values.

This part of ISO 1328 provides the gear manufacturer and the gear buyer with a mutually advantageous reference for uniform tolerances. Eleven flank tolerance classes are defined, numbered 1 to 11, in order of increasing tolerance. Formulae for tolerances are provided in 5.3. These tolerances are applicable to the following ranges:

$5 \le z \le 1\,000$

$5 \text{ mm} \le d \le 15\,000 \text{ mm}$

$0{,}5 \text{ mm} \le m_n \le 70 \text{ mm}$

$4 \text{ mm} \le b \le 1\,200 \text{ mm}$

$\beta \le 45°$

where

d is the reference diameter;

m_n is the normal module;

b is the facewidth (axial);

z is the number of teeth;

β is the helix angle.

See Clause 4 for required and optional measuring methods.

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Gear design is beyond the scope of this part of ISO 1328.

Surface texture is not considered in this part of ISO 1328. For additional information on surface texture, see ISO/TR 10064-4.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable to its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 701, *International gear notation — Symbols for geometrical data*

ISO 1122-1, *Vocabulary of gear terms — Part 1: Definitions related to geometry*

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

ISO/TR 10064-1, *Code of inspection practice — Part 1: Inspection of corresponding flanks of gear teeth*

ISO/TS 16610-1, *Geometrical product specifications (GPS) — Filtration — Part 1: Overview and basic concepts*

ISO 16610-21, *Geometrical product specifications (GPS) — Filtration — Part 21: Linear profile filters: Gaussian filters*

ISO 21771, *Gears — Cylindrical involute gears and gear pairs — Concepts and geometry*

3 Terms, definitions and symbols

3.1 Fundamental terms and symbols

For the purposes of this part of ISO 1328, the following terms, definitions and symbols apply.

NOTE 1 For other definitions of geometric terms related to gearing, see ISO 701, ISO 1122-1 and ISO 21771.

NOTE 2 Some of the symbols and terminology contained in this part of ISO 1328 might differ from those used in other documents and International Standards.

NOTE 3 The terminology and symbols used in this part of ISO 1328 are listed, in alphabetical order, by term in Table 1, and in alphabetical order, by symbol in Table 2. The text of terms used in Table 1 has been adjusted to form groups of logical terms. Subscript “T” is used for tolerance values.

Table 1 — Terms, listed in alphabetical order, with symbols

Term	Symbol	Unit
Active tip diameter	d_{Na}	mm
Active tip diameter point on line of action	N_a	–
Adjacent pitch difference	f_u	µm
Adjacent pitch difference tolerance	f_{uT}	µm
Adjacent pitch difference, individual	f_{ui}	µm
Amount of root relief	$C_{\alpha f}$	µm
Amount of tip relief	$C_{\alpha a}$	µm
Base diameter	d_b	mm
Contact pattern evaluation	c_p	–
Contact point tangent at base circle	T	–

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Table 1 *(continued)*

Term	Symbol	Unit
Cumulative pitch deviation (index deviation), individual	F_{pi}	µm
Cumulative pitch deviation (index deviation), total	F_p	µm
Cumulative pitch (index) tolerance, total	F_{pT}	µm
Facewidth (axial)	b	mm
Flank tolerance class	A	–
Helix angle	β	deg
Helix deviation, total	F_β	µm
Helix evaluation length	L_β	mm
Helix form deviation	$f_{f\beta}$	µm
Helix form filter cutoff	λ_β	mm
Helix form tolerance	$f_{f\beta T}$	µm
Helix slope deviation	$f_{H\beta}$	µm
Helix slope tolerance	$f_{H\beta T}$	µm
Helix tolerance, total	$F_{\beta T}$	µm
Individual radial measurement	r_i	µm
Length of path of contact	g_α	mm
Maximum length of tip relief	$L_{C\alpha a,max}$	mm
Maximum length of root relief	$L_{C\alpha f,max}$	mm
Measurement diameter	d_M	mm
Middle profile zone	$L_{\alpha m}$	–
Minimum length of tip relief	$L_{C\alpha a,min}$	mm
Minimum length of root relief	$L_{C\alpha f,min}$	mm
Normal module	m_n	mm
Number of teeth	z	–
Number of pitches in a sector	k	–
Pitch, transverse circular on measurement diameter	p_{tM}	mm
Pitch point	C	–
Pitch span deviation	F_{pSk}	µm
Profile control diameter	d_{Cf}	mm
Profile deviation, total	F_α	µm
Profile evaluation length	L_α	mm
Profile form deviation	$f_{f\alpha}$	µm
Profile form filter cutoff	λ_α	mm
Profile form tolerance	$f_{f\alpha T}$	µm
Profile slope deviation	$f_{H\alpha}$	µm
Profile slope tolerance	$f_{H\alpha T}$	µm
Profile tolerance, total	$F_{\alpha T}$	µm
Radial composite deviation, tooth-to-tooth[a]	f_i''	µm
Radial composite deviation, total[a]	F_i''	µm

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Table 1 *(continued)*

Term	Symbol	Unit
Reference diameter	d	mm
Root form diameter	d_{Ff}	mm
Root relief zone	$L_{C\alpha f}$	–
Runout	F_r	µm
Sector pitch deviation	F_{pk}	µm
Sector pitch tolerance	F_{pkT}	µm
Single flank composite deviation, total	F_{is}	µm
Single flank composite tolerance, total	F_{isT}	µm
Single flank composite deviation, tooth-to-tooth	f_{is}	µm
Single flank composite tolerance, tooth-to-tooth	f_{isT}	µm
Single pitch deviation	f_p	µm
Single pitch deviation (individual)	f_{pi}	µm
Single pitch tolerance	f_{pT}	µm
Start of active profile diameter	d_{Nf}	mm
Start of active profile point on line of action	N_f	–
Tip corner chamfer	h_k	mm
Tip diameter	d_a	mm
Tip form diameter	d_{Fa}	mm
Tip relief zone	$L_{C\alpha a}$	–
Tooth thickness	s	mm
Working pitch diameter	d_w	mm
Working transverse pressure angle	α_{wt}	deg
[a] Symbols given in ISO 1328-2.		

Table 2 — Symbols, listed in alphabetical order, with terms

Symbol	Term	Unit
A	Flank tolerance class	–
b	Facewidth (axial)	mm
C	Pitch point	–
$C_{\alpha a}$	Amount of tip relief	µm
$C_{\alpha f}$	Amount of root relief	µm
c_p	Contact pattern evaluation	–
d	Reference diameter	mm
d_a	Tip diameter	mm
d_b	Base diameter	mm
d_{Cf}	Profile control diameter	mm
d_{Fa}	Tip form diameter	mm
d_{Ff}	Root form diameter	mm
d_M	Measurement diameter	mm

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Table 2 *(continued)*

Symbol	Term	Unit
d_{Na}	Active tip diameter	mm
d_{Nf}	Start of active profile diameter	mm
d_w	Working pitch diameter	mm
F_i''	Radial composite deviation, total[a]	µm
F_{is}	Single flank composite deviation, total	µm
F_{isT}	Single flank composite tolerance, total	µm
F_p	Cumulative pitch deviation (index deviation), total	µm
F_{pi}	Cumulative pitch deviation (index deviation), individual	µm
F_{pk}	Sector pitch deviation	µm
F_{pkT}	Sector pitch tolerance	µm
F_{pT}	Cumulative pitch (index) tolerance, total	µm
F_{pSk}	Pitch span deviation	µm
F_r	Runout	µm
F_α	Profile deviation, total	µm
$F_{\alpha T}$	Profile tolerance, total	µm
F_β	Helix deviation, total	µm
$F_{\beta T}$	Helix tolerance, total	µm
$f_{f\alpha}$	Profile form deviation	µm
$f_{f\alpha T}$	Profile form tolerance	µm
$f_{f\beta}$	Helix form deviation	µm
$f_{f\beta T}$	Helix form tolerance	µm
$f_{H\alpha}$	Profile slope deviation	µm
$f_{H\alpha T}$	Profile slope tolerance	µm
$f_{H\beta}$	Helix slope deviation	µm
$f_{H\beta T}$	Helix slope tolerance	µm
f_i''	Radial composite deviation, tooth-to-tooth[a]	µm
f_{is}	Single flank composite deviation, tooth-to-tooth	µm
f_{isT}	Single flank composite tolerance, tooth-to-tooth	µm
f_p	Single pitch deviation	µm
f_{pi}	Single pitch deviation (individual)	µm
f_{pT}	Single pitch tolerance	µm
f_u	Adjacent pitch difference	µm
f_{ui}	Adjacent pitch difference, individual	µm
f_{uT}	Adjacent pitch difference tolerance	µm
g_α	Length of path of contact	mm
h_k	Tip corner chamfer	mm
k	Number of pitches in a sector	–
$L_{\alpha m}$	Middle profile zone	–
$L_{C\alpha a}$	Tip relief zone	–

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Table 2 *(continued)*

Symbol	Term	Unit
$L_{C\alpha f}$	Root relief zone	–
$L_{c\alpha a,max}$	Maximum length of tip relief	mm
$L_{c\alpha a,min}$	Minimum length of tip relief	mm
$L_{c\alpha f,max}$	Maximum length of root relief	mm
$L_{c\alpha f,min}$	Minimum length of root relief	mm
L_{α}	Profile evaluation length	mm
L_{β}	Helix evaluation length	mm
m_n	Normal module	mm
N_a	Active tip diameter point on line of action	–
N_f	Start of active profile point on line of action	–
p_{tM}	Pitch, transverse circular on measurement diameter	mm
r_i	Individual radial measurement	µm
s	Tooth thickness	mm
T	Contact point at tangent at base circle	–
z	Number of teeth	–
α_{wt}	Working transverse pressure angle	deg
β	Helix angle	deg
λ_{α}	Profile form filter cutoff	mm
λ_{β}	Helix form filter cutoff	mm
[a] Symbols given in ISO 1328-2.		

3.2 General dimensions

3.2.1
reference diameter
d
diameter of reference circle

Note 1 to entry: The reference diameter is used to calculate values of tolerances.

Note 2 to entry: See ISO 21771:2007, 4.2.4.

3.2.2
measurement diameter
d_M
diameter of the circle concentric with the *datum axis* (3.2.7) where the probe is in contact with the tooth flanks during the measurement of helix, pitch or tooth thickness deviations

Note 1 to entry: The measurement diameter is usually near the middle of the flank.

Note 2 to entry: See ISO/TR 10064-3.

3.2.3
profile form filter cutoff
λ_{α}
wavelength where 50 % of the amplitude of the involute profile measurement data is transmitted as a result of the Gaussian low-pass filter, thereby including only longer wavelength deviations

Note 1 to entry: See 4.4.6 and Annex C.

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3.2.4
helix form filter cutoff
λ_β
wavelength where 50 % of the amplitude of the helix measurement data is transmitted as a result of the Gaussian low-pass filter, thereby including only longer wavelength deviations

Note 1 to entry: See 4.4.6 and Annex C.

3.2.5
roll path length
length of roll
linear distance along a base tangent line from its contact with the base circle to the given point on the involute profile in the transverse plane

Note 1 to entry: Roll path length is an alternative to roll angle for specification of selected diameter positions on an involute profile.

Note 2 to entry: See Figure 1 and ISO 21771:2007, 4.3.8.

3.2.6
length of path of contact
g_α
roll path length (3.2.5) from the start of active profile, d_{Nf}, to the tip form diameter, d_{Fa}, or to the point where contact stops due to undercut on the mating part (end of active profile)

3.2.7
datum axis
axis to which the gear details, and in particular the pitch, profile and helix tolerances, are defined

Note 1 to entry: The datum axis of the gear is defined by the datum surfaces.

Note 2 to entry: See ISO/TR 10064-3.

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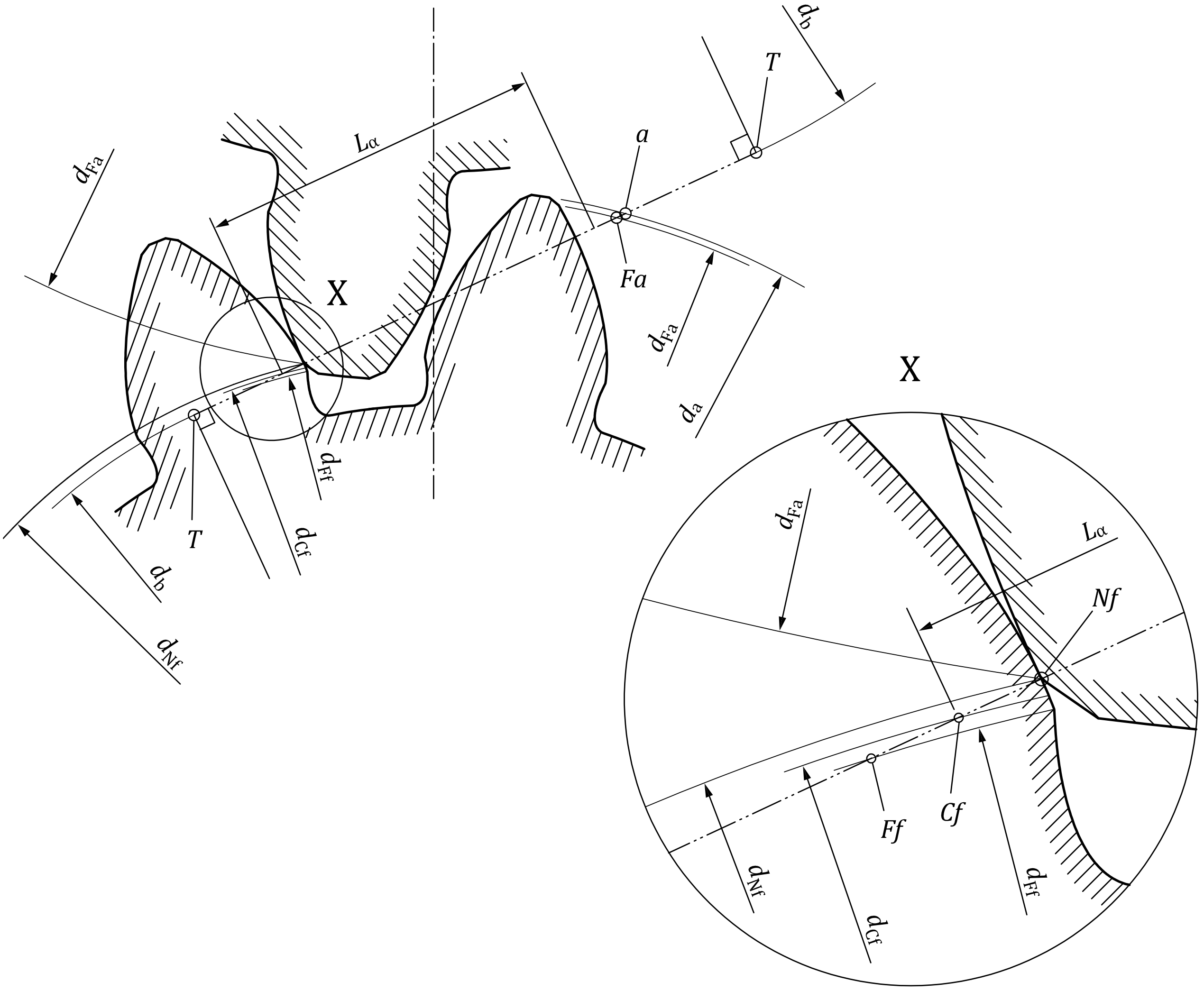

Key

L_α evaluation length

Points on line of action

a tip

Cf profile control

Fa tip form

Ff root form

Nf start of active profile

T tangency to base circle

— · · — — · · — line of action

Diameters

d_a tip

d_b base

d_{Cf} profile control

d_{Fa} tip form, where tip break starts

d_{Ff} root form, where involute starts

d_{Nf} start of active profile

NOTE Diameters on mating gear have the same symbols, but different values.

Figure 1 — Diameters and roll path length for an external gear pair

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3.3 Pitch deviations

3.3.1
individual single pitch deviation

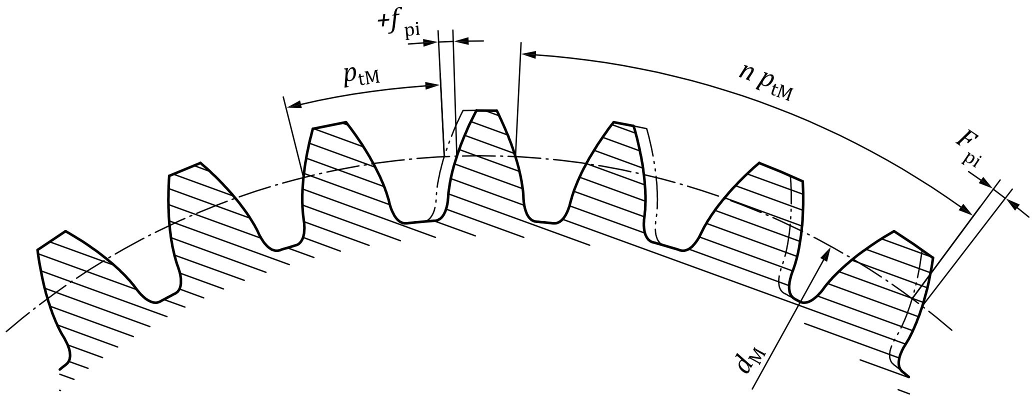
f_{pi}

algebraic difference between the actual pitch and the corresponding theoretical pitch in the transverse plane on the measurement circle of the gear

Note 1 to entry: It corresponds to the displacement of any tooth flank from its theoretical position relative to the corresponding flank of an adjacent tooth.

Note 2 to entry: For the left flanks, as well as for the right flanks, there are as many values of f_{pi} as there are teeth.

Note 3 to entry: See Figure 2.



Key

—··—··— theoretical

——— actual

NOTE $p_{tM} = \pi\, d_M/z$.

Figure 2 — Pitch deviations

3.3.2
single pitch deviation

f_p

maximum absolute value of all the *individual single pitch deviations* (3.3.1) observed

Note 1 to entry: $f_p = \max |f_{pi}|$.

3.3.3
individual cumulative pitch deviation

individual index deviation

F_{pi}

algebraic difference, over a sector of n adjacent pitches, between the length and the theoretical length of the relevant arc

Note 1 to entry: n varies from 1 to z; for the left flanks, as well as the right flanks, there are as many values of F_{pi} as there are teeth.

Note 2 to entry: In theory, it is equal to the algebraic sum of the individual single pitch deviations (3.3.1) of the same n pitches. It corresponds to the displacement of any tooth flank from its theoretical position, relative to a datum tooth flank.

Note 3 to entry: See Figure 2 and Annex D.

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3.3.4
total cumulative pitch deviation
total index deviation
F_p
largest algebraic difference between the *individual cumulative pitch deviation* (3.3.3) values for a specified flank obtained for all the teeth of a gear

Note 1 to entry: F_p = max. F_{pi} – min. F_{pi}.

3.4 Profile deviations

3.4.1 Profile deviations — General

3.4.1.1
profile control diameter
start of profile evaluation diameter
d_{Cf}
specified diameter beyond which the tooth profile is required to conform to the specified *design profile* (3.4.2.1)

Note 1 to entry: If not specified, the start of active profile diameter, d_{Nf}, is used as the profile control diameter, see the last paragraph of 4.5.

Note 2 to entry: See Figures 1 and 3.

3.4.1.2
tip form diameter
d_{Fa}
unless otherwise specified, tip diameter minus twice the tip corner radius or chamfer

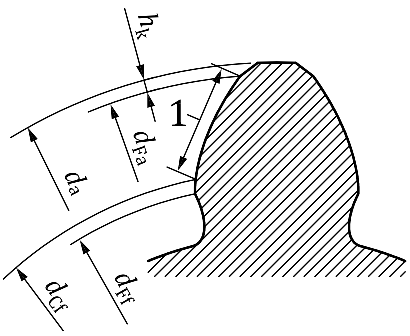
Note 1 to entry: This is the minimum specified diameter for external gears or maximum specified diameter for internal gears where the tip break (start of tip chamfer or tip corner radius) can occur.

Note 2 to entry: With direct transition between the nominal involute helicoid and the top land of the tooth, the tip corner radius is zero and the tip form diameter is equal to the tip diameter.

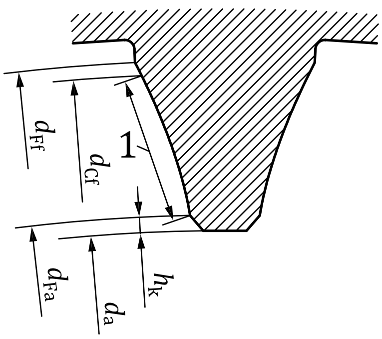
Note 3 to entry: See Figures 1 and 3.

3.4.1.3
measured profile
portion of the tooth flank along which the probe is in contact during the profile measurement, which shall include the *profile control diameter* (3.4.1.1)and the *tip form diameter* (3.4.1.2)

Note 1 to entry: See Figure 3.



a) External gear



b) Internal gear

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Key

1 measured profile

Figure 3 — Measured profile

3.4.1.4
profile evaluation range
section of the *measured profile* (3.4.1.3) starting at the profile control diameter (3.4.1.1), d_{Cf}, and, unless otherwise specified, ending at 95 % of the length to the tip form diameter (3.4.1.2), d_{Fa}

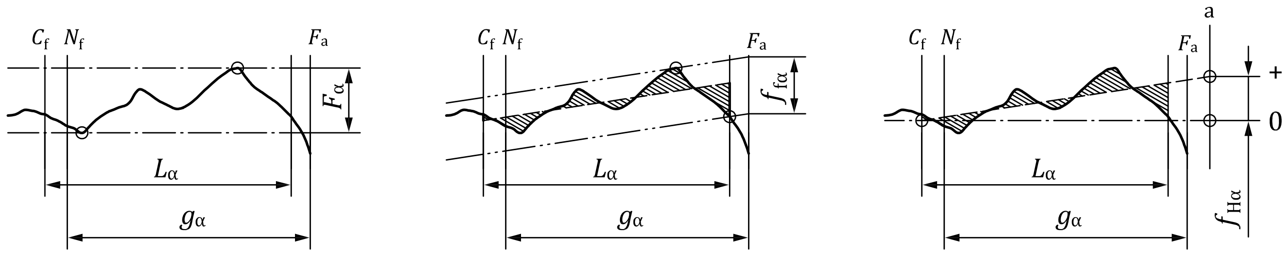
Note 1 to entry: See Figures 4 to 8, 4.4.8 and ISO 21771.

3.4.1.5
profile evaluation length
L_α
roll path length (3.2.5) of the *profile evaluation range* (3.4.1.4) in a transverse plane

Note 1 to entry: See Figure 1.

3.4.1.6
profile deviation
amount by which a *measured profile* (3.4.1.3) deviates from the *design profile* (3.4.2.1)

Note 1 to entry: See Figures 4 to 8.



Key

————————	measured profile	Points on line of action	
—·—·—·—·—	facsimile of design profile	C_f	profile control
— — — — — — —	mean profile line	N_f	start of active profile
——··——··——	facsimile of mean profile line	F_a	tip form, where tip break starts
		a	tip

Figure 4 — Profile deviations with unmodified involute

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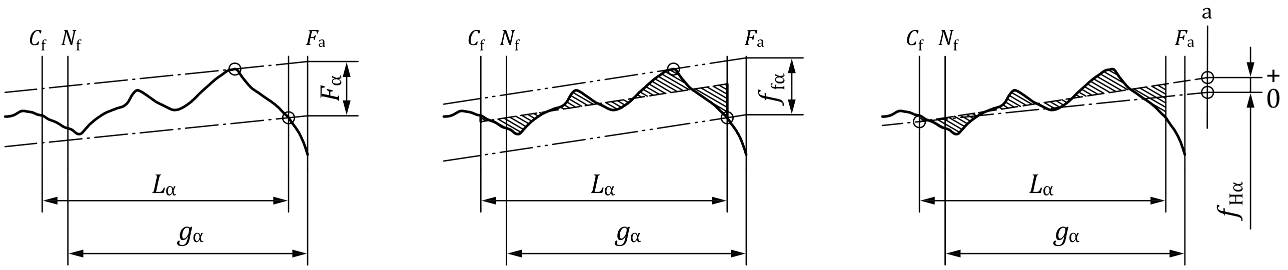


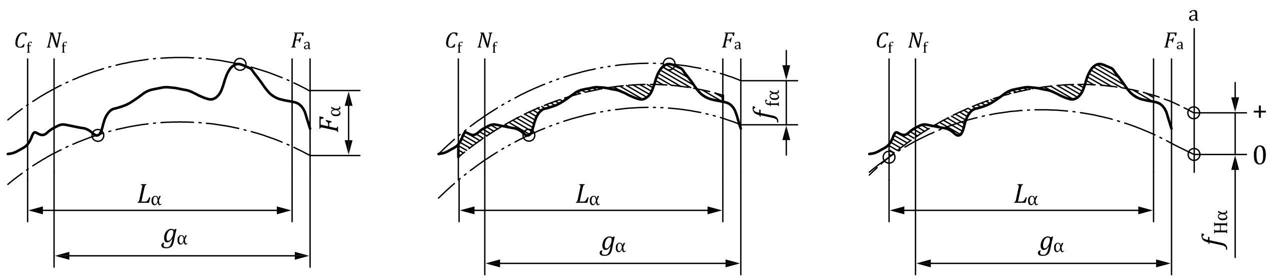
a) Total profile deviation

b) Profile form deviation

c) Profile slope deviation

See the key to Figure 4.

Figure 5 — Profile deviations with pressure angle modified



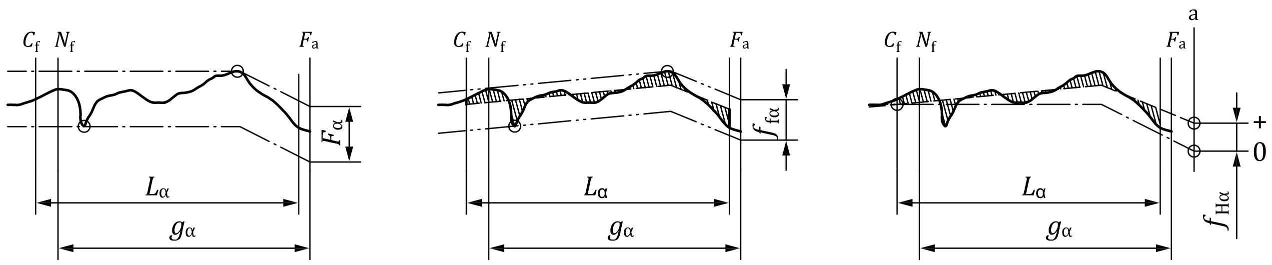
a) Total profile deviation

b) Profile form deviation

c) Profile slope deviation

See the key to Figure 4.

Figure 6 — Profile deviations with profile crowning modification



a) Total profile deviation

b) Profile form deviation

c) Profile slope deviation

See the key to Figure 4.

Figure 7 — Profile deviations with profile modified with tip relief

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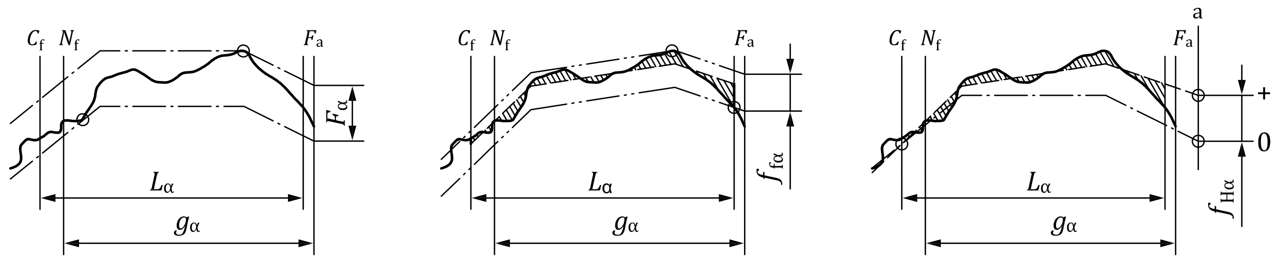

a) Total profile deviation b) Profile form deviation c) Profile slope deviation

See the key to Figure 4.

Figure 8 — Profile deviations with profile modified with tip and root relief

3.4.2 Analysis of profile deviations

3.4.2.1
design profile
profile specified by the designer in a diagram where one axis has modifications from a pure involute and the other axis has the roll length along the tangent to the base circle

Note 1 to entry: When the design profile is not specified, it is an unmodified involute and appears as a straight line. In Figures 4 to 8, the design profiles are shown as broken-chain (dotted) lines.

Note 2 to entry: See Figures 4 to 8.

3.4.2.2
mean profile line
line (or curve) that represents the shape of the *design profile* (3.4.2.1), but aligned with the measured trace over the *profile evaluation range* (3.4.1.4)

Note 1 to entry: See 4.4.8.2 for the method to be used.

3.4.2.3
profile deviation, total
F_α
distance between two facsimiles of the *design profile* (3.4.2.1) which enclose the *measured profile* (3.4.1.3) over the *profile evaluation range* (3.4.1.4)

Note 1 to entry: The facsimiles of the design profile are kept parallel to the design profile.

Note 2 to entry: See Figures 4 to 8 and 4.4.8.2.

3.4.2.4
profile form deviation
$f_{f\alpha}$
distance between two facsimiles of the *mean profile line* (3.4.2.2) which enclose the *measured profile* (3.4.1.3) over the *profile evaluation range* (3.4.1.4)

Note 1 to entry: The facsimiles of the mean profile line are kept parallel to the mean profile line.

Note 2 to entry: See Figures 4 to 8 and 4.4.8.2.

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3.4.2.5
profile slope deviation
$f_{H\alpha}$
distance between two facsimiles of the *design profile* (3.4.2.1) which intersect the extrapolated *mean profile line* (3.4.2.2) at the *profile control diameter* (3.4.1.1), d_{Cf}, and the tip diameter, d_a

Note 1 to entry: The facsimiles of the design profile are kept parallel to the design profile.

Note 2 to entry: See Figures 4 to 8.

3.5 Helix deviations

3.5.1 Helix deviations — General

3.5.1.1
measured helix
full flank between the end faces or, if present, the start of end chamfers, rounds, or other modification intended to exclude that portion of the tooth from engagement, along which the probe is in contact during the helix measurement

3.5.1.2
helix evaluation range
flank area between the end faces or, if present, the start of end chamfers, rounds, or other modification intended to exclude that portion of the tooth from engagement, that is, unless otherwise specified, shortened in the axial direction at each end by the smaller of 5 % of the facewidth or the length equal to one module

Note 1 to entry: It is the responsibility of the gear designer to ensure that the helix evaluation range is adequate for the application.

Note 2 to entry: See 4.4.8.4.

3.5.1.3
helix evaluation length
L_β
axial length of the *helix evaluation range* (3.5.1.2)

3.5.1.4
helix deviation
amount by which a *measured helix* (3.5.1.1) deviates from the *design helix* (3.5.2.1)

Note 1 to entry: See Figures 9 to 13.

3.5.2 Analysis of helix deviations

3.5.2.1
design helix
helix specified by the designer in a diagram where one axis has modifications from a pure helix and the other axis has the facewidth

Note 1 to entry: When not specified, it is an unmodified helix.

Note 2 to entry: See Figures 9 to 13.

3.5.2.2
mean helix line
line (or curve) that represents the shape of the *design helix* (3.5.2.1), but aligned with the measured trace

Note 1 to entry: See 4.4.8.4 for the method to be used.

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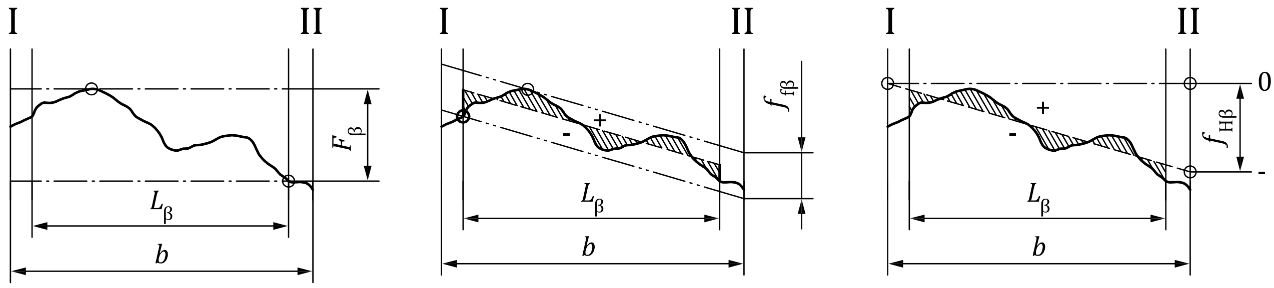
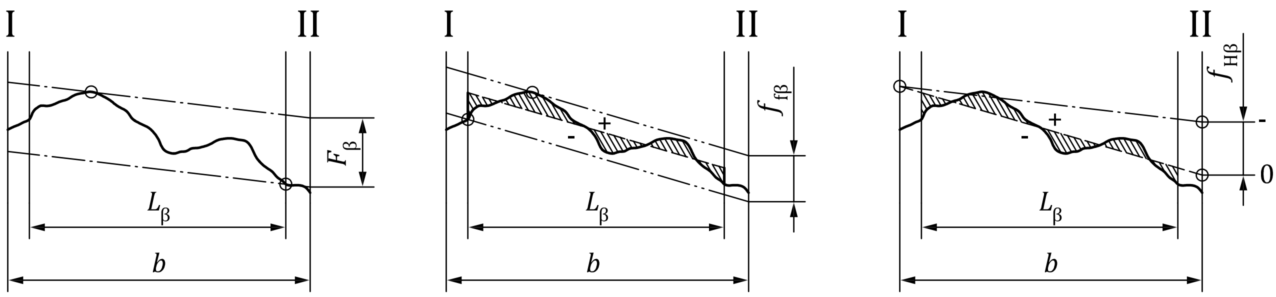


a) **Total helix deviation** b) **Helix form deviation** c) **Helix slope deviation**

Key

- ———————— measured helix
- — — — — — — — mean helix line
- —.—.—.—.— facsimile of design helix
- —..—..—..— facsimile of mean helix line

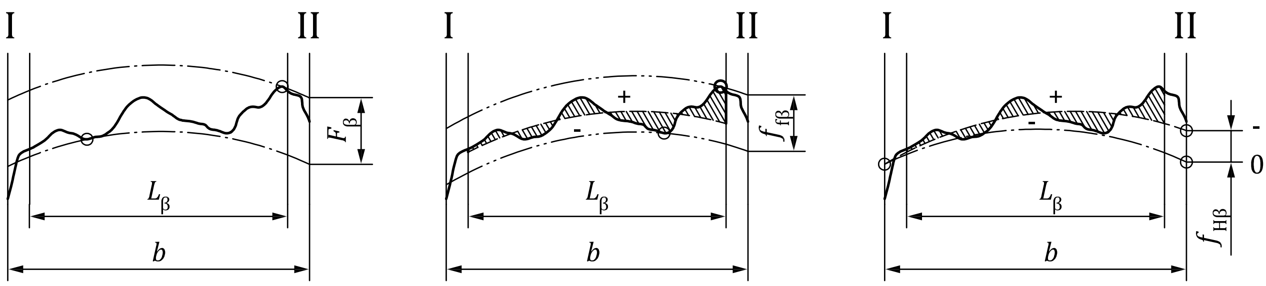
Figure 9 — Helix deviations with unmodified helix



a) **Total helix deviation** b) **Helix form deviation** c) **Helix slope deviation**

See the key to Figure 9.

Figure 10 — Helix deviations with helix angle modification



a) **Total helix deviation** b) **Helix form deviation** c) **Helix slope deviation**

See the key to Figure 9.

Figure 11 — Helix deviations with helix crowning modification

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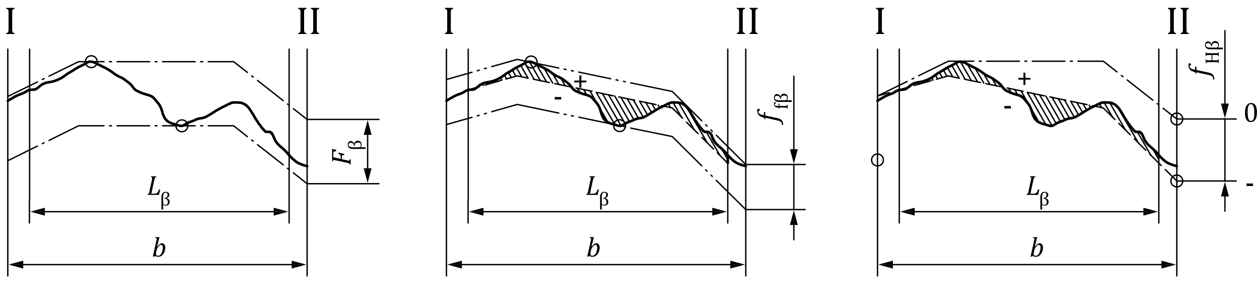
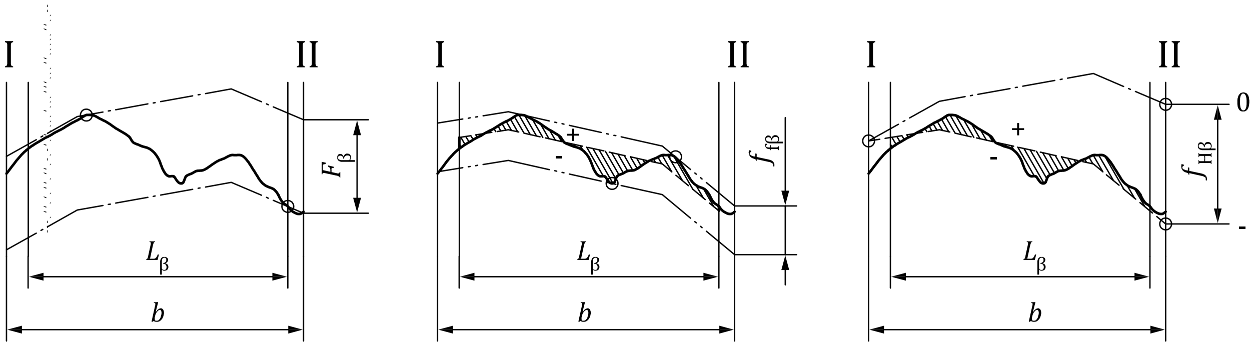


a) Total helix deviation **b) Helix form deviation** **c) Helix slope deviation**

See the key to Figure 9.

Figure 12 — Helix deviations with helix end relief



a) Total helix deviation **b) Helix form deviation** **c) Helix slope deviation**

See the key to Figure 9.

Figure 13 — Helix deviations with modified helix angle with end relief

3.5.2.3
helix deviation, total
$F_β$
distance between two facsimiles of the *design helix* (3.5.2.1) which enclose the *measured helix* (3.5.1.1) over the *helix evaluation range* (3.5.1.2)

Note 1 to entry: The facsimiles of the design helix are kept parallel to the design helix.

Note 2 to entry: See Figures 9 to 13 and 4.4.8.4.

3.5.2.4
helix form deviation
$f_{fβ}$
distance between two facsimiles of the *mean helix line* (3.5.2.2), which enclose the *measured helix* (3.5.1.1) over the *helix evaluation range* (3.5.1.2)

Note 1 to entry: The facsimiles of the mean helix line are kept parallel to the mean helix line.

Note 2 to entry: See Figures 9 to 13 and 4.4.8.4.

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3.5.2.5
helix slope deviation
$f_{H\beta}$
distance between two facsimiles of the *design helix* (3.5.2.1) which intersect the extrapolated *mean helix line* (3.5.2.2) at the end points of the facewidth, *b*

Note 1 to entry: The facsimiles of the design helix are kept parallel to the design helix.

Note 2 to entry: See Figures 9 to 13.

Note 3 to entry: See 4.4.8.4 for the method to be used.

4 Application of the ISO flank tolerance classification system

4.1 General

This part of ISO 1328 provides flank classification tolerances and recommends measuring requirements for unassembled gears.

Some design and application considerations can warrant measuring or documentation not normally available in standard manufacturing processes. Specific requirements shall be stated in the contractual documents.

No particular method of measurement or documentation is considered mandatory unless specifically agreed upon between the manufacturer and purchaser. When applications require measurements beyond those recommended in this part of ISO 1328, special measurement methods shall be negotiated prior to manufacturing the gear.

The designation as defined in 4.6.1 shall be used when specifying flank tolerance classes from this part of ISO 1328, since in the previous edition, the flank tolerance classes had different tolerance values.

4.2 Geometrical parameters to be verified

The geometrical features of a gear, listed in Table 3, may be measured by a number of methods. The selection of the particular method depends on the magnitude of the tolerance, the related measurement uncertainty, the size of the gear, the production quantities, equipment available, accuracy of gear blanks, and measurement costs. Measuring methods and practices for spur and helical gears are discussed in ISO/TR 10064-1.

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Table 3 — Parameters — Locations of definitions and tolerances

Parameter symbol	Measurement description	Location of tolerance	Location of definition
Elemental:			
F_p	Cumulative pitch (index), total	5.3.2	3.3.4
f_p	Single pitch	5.3.1	3.3.2
F_α	Profile, total	5.3.3.3	3.4.2.3
$f_{f\alpha}$	Profile form	5.3.3.2	3.4.2.4
$f_{H\alpha}$	Profile slope	5.3.3.1	3.4.2.5
F_β	Helix, total	5.3.4.3	3.5.2.3
$f_{f\beta}$	Helix form	5.3.4.2	3.5.2.4
$f_{H\beta}$	Helix slope	5.3.4.1	3.5.2.5
F_r	Runout	E.4	E.3
F_{pk}	Sector pitch	D.5	D.2
f_u	Adjacent pitch difference	G.2	G.1.2
Composite:			
F_{is}	Single flank composite, total	F.1.6	Annex F
f_{is}	Single flank composite, tooth-to-tooth	F.1.5	F.1.5
c_p	Contact pattern (see ISO/TR 10064-4)	–	
Size:			
s	Tooth thickness (see ISO 21771)	–	

A gear that is specified to an ISO flank tolerance class shall meet all the individual tolerance requirements applicable to the particular flank tolerance class and size as noted in Tables 4 and 5.

Table 4 contains lists of the minimum set of parameters that shall be checked for compliance with this part of ISO 1328. With agreement between the manufacturer and purchaser, the alternative list may be used instead of the default list. The selection of the default or alternative list may depend on the measuring instruments available. The parameter list for a more accurate flank tolerance class may be used when evaluating gears.

Normally, the tolerances apply to both sides of the teeth. In some cases, the loaded flank may specify better accuracy than the non-loaded or minimum-loaded flank; if applicable, this information and indication of the loaded flank shall be specified on the gear engineering drawing.

Table 4 — Parameters to be measured

Diameter mm	Flank tolerance class	Minimum acceptable parameters	
		Default parameter list	Alternative parameter list
$d \leq 4\,000$	10 to 11	$F_p, f_p, s, F_\alpha, F_\beta$	s, c_p[b], F_i''[a], f_i''[a]
	7 to 9	$F_p, f_p, s, F_\alpha, F_\beta$	s, c_p[b], F_{is}, f_{is}
	1 to 6	F_p, f_p, s $F_\alpha, f_{f\alpha}, f_{H\alpha}$ $F_\beta, f_{f\beta}, f_{H\beta}$	s, c_p[b], F_{is}, f_{is}
$d > 4\,000$	7 to 11	$F_p, f_p, s, F_\alpha, F_\beta$	F_p, f_p, s, ($f_{f\beta}$ or c_p[b])

[a] In accordance with ISO 1328-2, but only when size is not a constraint.

[b] Contact pattern acceptance criteria and measurement practice are not specified in this part of ISO 1328, and shall be agreed upon between the manufacturer and purchaser.

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Table 5 — Minimum number of measurements

Method designator	Typical measuring method	Minimum number of requirements
Elemental: F_p: Cumulative pitch (index), total	Two probe Single probe	All teeth All teeth
f_p: Single pitch	Two probe Single probe	All teeth All teeth
F_α: Profile, total $f_{f\alpha}$: Profile form $f_{H\alpha}$: Profile slope	Profile	Three teeth
F_β: Helix, total $f_{f\beta}$: Helix form $f_{H\beta}$: Helix slope	Helix	Three teeth
Composite: F_{is}: Single flank composite, total	–	All teeth
f_{is}: Single flank composite, tooth-to-tooth	–	All teeth
c_p: Contact pattern	–	Three places
Sizes: s: Tooth thickness	Chordal measurement Measurement over or between pins Span measurement Composite action test	Three teeth Two places Two places All teeth

Unless otherwise specified, the manufacturer shall select:

— the measurement method to be used from among the applicable methods described in ISO/TR 10064-1 and summarized in Table 5;

— the piece of measurement equipment to be used by the selected measurement method, provided it is in proper calibration;

— the individual teeth to be measured, as long as they are approximately equally spaced and meet the minimum number required by the method as summarized in Table 5.

4.3 Equipment verification and uncertainty

In order to ensure traceability, the equipment used for the measurement of gears should be verified periodically according to standard calibration procedures, such as those in ISO 18653. The uncertainty of the measuring process should be determined.

4.4 Considerations for elemental measurements

4.4.1 Summary of considerations

Before elemental measurement values can be compared with tolerance values, certain operational parameters of the measurement method shall be known. These include:

— datum axis;

— direction of measurement;

— direction of tolerance;

— measurement diameter;

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— data filtering;

— data density;

— required measuring practices.

In some cases, measurement instruments follow the minimum requirements by default. When other conditions exist, it is required that the causes of the measurement differences be known and compensated for.

It is important to distinguish between measurement location (the measurement diameter), measurement direction, and tolerance direction.

4.4.2 Datum axis

Specification of design profile, design helix and pitch requires the definition of an appropriate reference axis of rotation, called the datum axis. It is defined by specification of datum surfaces. See ISO/TR 10064-3.

The tooth geometry is determined with reference to the datum axis, so the datum axis is the reference for measurements and associated tolerances. The location and orientation of the measurement diameter circle are determined by the datum axis.

4.4.3 Direction of measurement

Measurements of the shape or the position of any surface may be made in a direction normal to that surface, inclined at some angle, or along the arc of a specified circle.

Common metrology practice is to measure in a direction normal to the surface being measured. At any point on a gear tooth surface, the normal vector is oriented a) tangent to the base cylinder of the gear, and b) inclined relative to the transverse plane at the base helix angle.

It is important to understand that gear measuring instruments use different measuring procedures, some measuring in the normal direction, some measuring in other directions.

4.4.4 Direction of tolerance

In this part of ISO 1328, the tolerance direction varies with the given elemental parameter. Original measurement values shall be compensated for if the actual measurement direction and the tolerance direction specified for the given parameter are different. See 4.4.8.2, 4.4.8.4 and 4.4.8.6 for sign conventions and the reporting of values.

The specified tolerance direction of measurement for all pitch deviations is in the transverse plane along the arc of the measurement diameter, d_M, circle.

The specified direction of tolerance for profile and helix deviations is in a transverse plane, on a line tangent to the base circle.

4.4.5 Measurement diameter

This part of ISO 1328 specifies the measurement diameter, d_M, as defined in 3.2.2 as the location for the measurement of helix and pitch parameters (also see 4.4.3 and 4.4.4). The measurement diameter shall be recorded on the inspection record. Since the tolerance values are calculated based on the reference diameter, they remain unchanged when the measurement diameter is modified.

When the measurement diameter is not specified, it is given by:

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for external gears:

$$d_M = d_a - 2m_n \tag{1}$$

for internal gears:

$$d_M = d_a + 2m_n \tag{2}$$

where

d_M is the measurement diameter, mm;

d_a is the tip diameter, mm;

m_n is the normal module, mm.

4.4.6 Measurement data filtering

Any tooth surface will exhibit a wide spectrum of deviations from the specified tooth flank form. This includes, at one extreme, those of long period, such as a general concavity. At the other end of the spectrum are short period irregularities, such as surface roughness.

This part of ISO 1328 requires the modification of original measurement values for involute profile and helix evaluation so as to include only long period irregularities before analysis and comparison to tolerances. This modification is called low-pass filtering. It minimizes or excludes irregularities with wavelengths shorter than the specified filter cutoff wavelength. The filter cutoff wavelength specified by this part of ISO 1328 is the gear form filter cutoff, λ_α or λ_β, as defined in 3.2.3 and 3.2.4. The profile form filter cutoff, λ_α, shall be stated in terms of roll path length. The helix form filter cutoff, λ_β, shall be stated in terms of facewidth. The recommended form filter cutoff may be calculated using Formulae (3) and (4). Form filter cutoff wavelengths longer than these shall not be used.

$$\lambda_\alpha = \frac{L_\alpha}{30} \tag{3}$$

but not less than 0,25 mm

$$\lambda_\beta = \frac{b}{30} \tag{4}$$

but not less than λ_α

where

λ_α is the profile form filter cutoff, mm;

λ_β is the helix form filter cutoff, mm.

The actual filter type and form filter cutoffs, λ_α and λ_β, along with the probe diameter, shall be indicated on the inspection record. A Gaussian 50 % type filter is required and defined in accordance with ISO/TS 16610-1 and ISO 16610-21.

WARNING — There are some cases where the filtering based on the form filter cutoff wavelength values recommended in Formulae (3) and (4) may suppress form deviations which are relevant to the function of the gear. Form deviations that exist with a wavelength between the recommended form filter cutoff and the filter cutoff used for surface roughness are sometimes referred to as waviness. When specified, form filter cutoff wavelengths that are shorter than those specified in Formulae (3) and (4) should be selected to evaluate such form deviations.

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See Annex C for additional information.

4.4.7 Measurement data density

Measurement data density is closely related to measurement data filtering in that the data sampling rate limits the wavelength of surface irregularities which can be observed. The number of data points included in the evaluation length shall be shown on the inspection record. Involute profile measurement data sets shall include a minimum of 150 points approximately equally spaced along the length of roll. Helix measurement data sets shall include a minimum of $5 \cdot b/\lambda_\beta$ points. If waviness is to be checked, then the data set shall include a minimum of 300 points or 5 points per millimetre, whichever is the greater.

4.4.8 Required measuring and evaluation practices

4.4.8.1 Profile measurement

The measurement probe shall travel the full profile length. The probe shall start below the profile control diameter and continue past where the tip break actually starts.

4.4.8.2 Profile analysis

Within the profile evaluation range, the straight-line gradient of the profile measurement is found by applying the least squares method to the deviation of the measured profile trace from the specified design profile. The evaluation always starts at the profile control diameter d_{Cf}. Deviations caused by plus material beyond the profile evaluation range near the tip of the tooth shall be included in the calculation of the profile form deviation, $f_{f\alpha}$, and total profile deviation, F_α. Minus material beyond the profile evaluation range near the tip of the tooth may be ignored (see Figure 14).

a) Total profile deviation **b) Profile form deviation**

Key

———— measured profile	Points on line of action
—·—·— facsimile of design profile	C_f profile control
– – – – mean profile line	N_f start of active profile
—··—··— facsimile of mean profile line	F_a tip form, where tip break starts

Figure 14 — Profile excess

The mean profile line is developed by adding the ordinates of the straight-line gradient of the profile deviation to the ordinates of the design profile. The mean profile line is used to determine $f_{f\alpha}$ [see Figures 4 b), 5 b), 6 b), 7 b), 8 b) and 14 b)] and $f_{H\alpha}$ [see Figures 4 c), 5 c), 6 c), 7 c) and 8 c)].

For both internal and external gears, the profile slope deviation is deemed to be positive and the corresponding pressure angle deviation is deemed to be negative when the mean profile line shows an increase in material toward the tooth tip, relative to the design profile.

The profile is evaluated over the profile evaluation range, but for determination of the profile slope deviation the result is extrapolated to the tip diameter.

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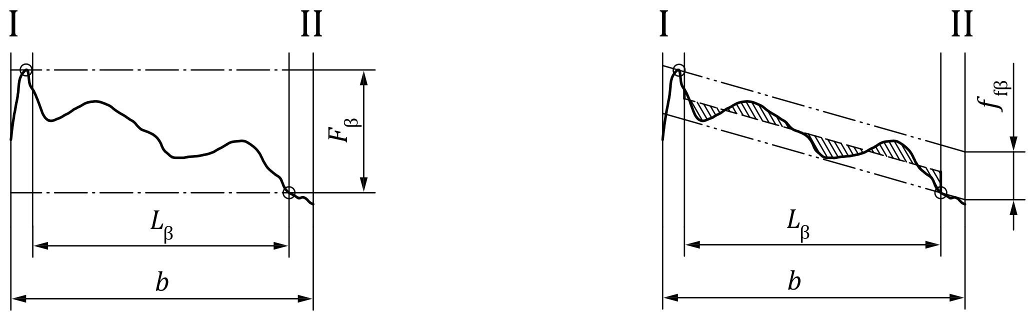
4.4.8.3 Helix measurement

The measurement probe shall travel the full facewidth, from end face to end face, or, if present, from the start of end chamfers, rounds, or other modification intended to exclude that portion of the tooth from engagement.

4.4.8.4 Helix analysis

Within the helix evaluation range, the straight-line gradient of the helix measurement is found by applying the least squares method to the deviation of the measured helix trace from the specified design helix. Deviations caused by plus material outside the helix evaluation range shall be included in the calculation of helix form deviation, $f_{f\beta}$, and total helix deviation, F_β. Minus material outside the helix evaluation range may be ignored (see Figure 15).



a) Total helix deviation **b) Helix form deviation**

Figure 15 — Helix excess

The mean helix line is developed by adding the ordinates of the straight-line gradient of the helix deviation to the ordinates of the design helix. The mean helix line is used to determine $f_{f\beta}$ [see Figures 9 b), 10 b), 11 b), 12 b), 13 b) and 15 b)] and $f_{H\beta}$ [see Figures 9 c), 10 c), 11 c), 12 c) and 13 c)].

Helix slope deviations are deemed to be positive when the absolute values of the helix angles are larger, and negative when helix angles are smaller, than the designed helix angle. The helix slope deviations of spur gears are deemed + (positive) if right hand and – (negative) if left hand.

4.4.8.5 Measurement location

Helix measurements shall be at the measurement diameter. Pitch measurements shall be at the measurement diameter unless the pitch measurements are used to evaluate tooth thickness. In this case the pitch measurement diameter should be the appropriate contacting diameter for the selected evaluation method (dimension over/under pins or ball measurement, chordal or circular tooth thickness). The reference diameter, d, shall be used for calculating the tolerance values in accordance with Clause 5, irrespective of the measurement diameter.

4.4.8.6 Reporting of pitch deviation values

4.4.8.6.1 Individual single pitch deviation

Distinction is made as to the algebraic sign of this reading. A condition wherein the actual tooth flank position is nearer to the previous tooth flank than the theoretical position is considered a minus (-) deviation. A condition wherein the actual tooth flank position is further from the previous tooth flank than the theoretical position is considered a plus (+) deviation.

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4.4.8.6.2 Single pitch deviation values

This value is reported without a sign. It is reported separately for both the left and right flanks on inspection records.

4.4.8.6.3 Individual cumulative pitch deviation

Distinction is made as to the direction and algebraic sign of this reading. In the specified measuring path direction [clockwise or counterclockwise (anticlockwise)], a condition wherein the actual tooth flank position is nearer to the datum tooth flank than the theoretical position is considered a minus (-) deviation, otherwise there is a plus (+) deviation.

4.4.8.6.4 Total cumulative pitch deviation

Distinction is not made as to the direction or algebraic sign of this reading. Such a distinction would require a purely arbitrary specification of a direction [clockwise or counterclockwise (anticlockwise)] between the two teeth comprising the total cumulative pitch deviation. It is reported separately for both the left and right flanks on inspection records.

4.5 Specification of gear flank tolerance requirements

The information to define the gear flank tolerance requirements on the gear drawing or gear specification should include, but should not be limited to:

— a reference to this part of ISO 1328, i.e. ISO 1328-1:2013;

— the flank tolerance class of each tolerance parameter, which may be different for each parameter, and the limits, in micrometres, calculated in accordance with this part of ISO 1328;

— datum axis used for measurement (preferably the functional datum axis; see ISO/TR 10064-3);

— functional datum axis (used for evaluation);

— measurement diameter if different from the recommendation in 4.4.5;

— the minimum number of teeth to be inspected, if different from the minimum recommendation in Table 5;

— the design shape for profile or helix modifications, if they are required;

— the range of evaluation for profile and helix measurement;

— the profile control diameter (defined as a diameter, length of roll or angle of roll);

— additional measurement requirements, for example tooth thickness (defined as circular thickness at reference diameter, span measurement or dimension over balls), tip and root diameter, root fillet profile, surface roughness of tooth flank.

It is usual to define this information as a table of data.

The designer may select the profile control diameter to be anywhere between the root form diameter and the start of active profile diameter. The root form diameter depends on either the undercut diameter, the point of tangency to the root fillet, or the base circle diameter (whichever is closest to the tip diameter). If a profile control diameter is not specified, the start of active profile diameter, d_{Nf},is used in place of the profile control diameter. When a gear will mesh with more than one mating gear, the start of active profile diameter should be considered for each of these gears when selecting the profile control diameter.

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4.6 Acceptance and evaluation criteria

4.6.1 Designation of flank tolerance class

Designation/specification of a flank tolerance class in accordance with this part of ISO 1328 shall be as follows:

ISO 1328-1:2013, class A

where A designates the design flank tolerance class.

NOTE If the year of publication is not listed, the latest version of ISO 1328-1 applies.

4.6.2 Modified flank tolerance class

For a given gear, it is permissible to use different flank tolerance classes for each tolerance parameter.

4.6.3 Tolerances

The tolerances for each item that govern the flank tolerance class of gears are calculated by the formulae given in Clause 5.

4.6.4 Acceptance criteria

The tolerances, methods, and definitions contained in this part of ISO 1328 prevail unless contractual agreements between the manufacturer and purchaser contain specific exceptions. See ISO 18653, ISO/TR 10064-5 and ISO 14253-1 for discussion on measurement uncertainty and how to apply to specified tolerances.

4.6.5 Evaluation of flank tolerance class

The overall flank tolerance class of a gear is determined by the largest flank tolerance class number measured for any tolerance parameter specified for the gear by this part of ISO 1328.

4.6.6 Additional characteristics

In certain applications there can be additional characteristics that might require tolerances in order to ensure satisfactory performance. For example, if dimensions for tooth thickness or surface finish tolerances are desirable in order to ensure satisfactory performance in special applications, such dimensions and tolerances should appear on drawings or purchase specifications. Methods of measuring some of these characteristics are discussed in ISO/TR 10064-1, and in Annexes D to G.

4.7 Presentation of data

Throughout this part of ISO 1328, all the figures show how the design or measured profile deviates from a theoretical pure involute with the design pressure angle or how the design or measured helix deviates from a theoretical pure helix with the design helix angle. The figures show the profile and helix as generally horizontal lines, so as not to require indication of left or right flank or internal or external gear. Most measuring machines display the profile and helix as generally vertical lines; the orientation is not important.

5 Tolerance values

5.1 General

Tolerance values are calculated, in micrometres, by Formulae (5) to (12) given in 5.3.

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5.2 Use of formulae

5.2.1 Range of application

The ranges of application are specified in the Scope (Clause 1), and Formulae (5) to (12) (in 5.3) shall not be extrapolated beyond these limits. Tolerances for gears beyond these ranges shall be agreed upon by the manufacturer and purchaser.

5.2.2 Step factor

The step factor between two consecutive classes is $\sqrt{2}$. Values of the next higher (or lower) class are determined by multiplying (or dividing) by $\sqrt{2}$. The required value for any flank tolerance class may be determined by multiplying the unrounded calculated value for class 5 by $\sqrt{2}^{(A-5)}$ where A is the number of the required flank tolerance class.

5.2.3 Rounding rules

Values calculated from Formulae (5) to (12) (in 5.3) shall be rounded as follows:

— if greater than 10 µm, round to the nearest integer micrometre;

— if 5,0 µm or greater but less than or equal to 10 µm, round to the nearest 0,5 µm;

— if less than 5,0 µm, round to the nearest 0,1 µm.

If the measuring instrument reads in (Imperial) inches, values calculated from Formulae (5) to (12) in 5.3 shall be converted to ten thousandths of an inch and then rounded according to the rules for micrometres (i.e. substitute "ten thousandths of an inch" for "micrometre" in the rules above). Parameters in Formulae (5) to (12) are intended to be entered in millimetres.

5.3 Tolerance formulae

5.3.1 Single pitch tolerance, f_{pT}

Single pitch tolerance, f_{pT}, shall be calculated using Formula (5):

$$f_{pT} = (0{,}001d + 0{,}4m_n + 5)\left(\sqrt{2}\right)^{(A-5)} \quad (5)$$

5.3.2 Cumulative pitch (index) tolerance, total, F_{pT}

Total cumulative pitch (index) tolerance, F_{pT}, shall be calculated using Formula (6):

$$F_{pT} = \left(0{,}002d + 0{,}55\sqrt{d} + 0{,}7m_n + 12\right)\left(\sqrt{2}\right)^{(A-5)} \quad (6)$$

5.3.3 Profile tolerances

5.3.3.1 Profile slope tolerance, $f_{H\alpha T}$

Profile slope tolerance, $f_{H\alpha T}$, shall be calculated using Formula (7). This tolerance shall be applied as a plus/minus (±) value.

$$f_{H\alpha T} = (0{,}4m_n + 0{,}001d + 4)\left(\sqrt{2}\right)^{(A-5)} \quad (7)$$

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5.3.3.2 Profile form tolerance, $f_{f\alpha T}$

Profile form tolerance, $f_{f\alpha T}$, shall be calculated using Formula (8):

$$f_{f\alpha T} = (0{,}55 m_n + 5)\left(\sqrt{2}\right)^{(A-5)} \quad (8)$$

5.3.3.3 Profile tolerance, total, $F_{\alpha T}$

Total profile tolerance, $F_{\alpha T}$, shall be calculated as given by Formula (9) using unrounded tolerance values for profile slope and profile form:

$$F_{\alpha T} = \sqrt{f_{H\alpha T}^2 + f_{f\alpha T}^2} \quad (9)$$

5.3.4 Helix tolerances

5.3.4.1 Helix slope tolerance, $f_{H\beta T}$

Helix slope tolerance, $f_{H\beta T}$, shall be calculated using Formula (10). This tolerance shall be applied as a plus/minus (±) value.

$$f_{H\beta T} = \left(0{,}05\sqrt{d} + 0{,}35\sqrt{b} + 4\right)\left(\sqrt{2}\right)^{(A-5)} \quad (10)$$

5.3.4.2 Helix form tolerance, $f_{f\beta T}$

Helix form tolerance, $f_{f\beta T}$, shall be calculated using Formula (11):

$$f_{f\beta T} = \left(0{,}07\sqrt{d} + 0{,}45\sqrt{b} + 4\right)\left(\sqrt{2}\right)^{(A-5)} \quad (11)$$

5.3.4.3 Helix tolerance, total, $F_{\beta T}$

Total helix tolerance, $F_{\beta T}$, shall be calculated as given by Formula (12) using unrounded tolerance values for helix slope and helix form:

$$F_{\beta T} = \sqrt{f_{H\beta T}^2 + f_{f\beta T}^2} \quad (12)$$

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Annex A
(normative)

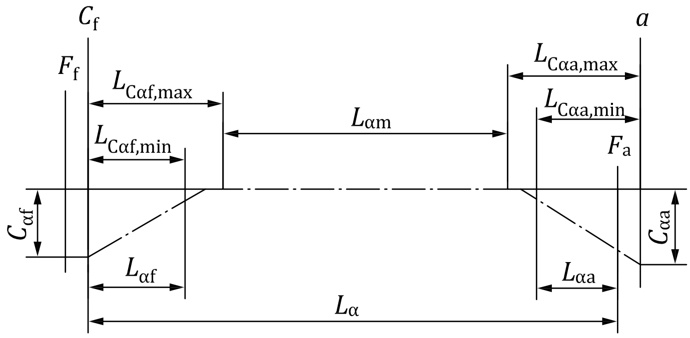
Zone-based tolerance evaluation

A.1 General

This annex presents a strategy using a segmented evaluation or zone evaluation for two or more zones. An example for the gear profile can be a tip zone, middle zone and root zone. Adjacent zones are calculated separately, and can have different tolerance classes.

A.2 Zone-based profile tolerance evaluation

For the determination of the slope and form deviation a regression calculation is necessary. In the case of tip and root modifications, each zone may be considered separately (see Figure A.1). For the calculation of the regression lines, only the zones $L_{\alpha a}$, $L_{\alpha m}$ and $L_{\alpha f}$ are used. The areas between the zones are only considered for the plus material condition for form and total deviation. The length of these areas shall be defined and cannot be zero (except when there is a tangential transition). The regression is calculated on the deviations from the design profile according to the sum of the least squares (Gauss). In most cases, a linear regression is used.



Key

$C_{\alpha a}$	amount of tip relief	Points on line of action	
$C_{\alpha f}$	amount of root relief	a	tip
$L_{C\alpha a,max}$	maximum length of tip relief	C_f	profile control
$L_{C\alpha a,min}$	minimum length of tip relief	F_a	tip form
$L_{C\alpha f,max}$	maximum length of root relief	F_f	root form
$L_{C\alpha f,min}$	minimum length of root relief		
$L_{\alpha a}$	tip relief zone		
$L_{\alpha m}$	middle profile zone		
$L_{\alpha f}$	root relief zone		

Figure A.1 — Regression zones for profile with tip and root modification

A.2.1 Profile slope deviation, $f_{H\alpha}$

For the profile slope deviation, $f_{H\alpha}$, the regression line of the middle profile zone shall be extrapolated over the area from the profile control point to the tip [see Figure A.2 c)].

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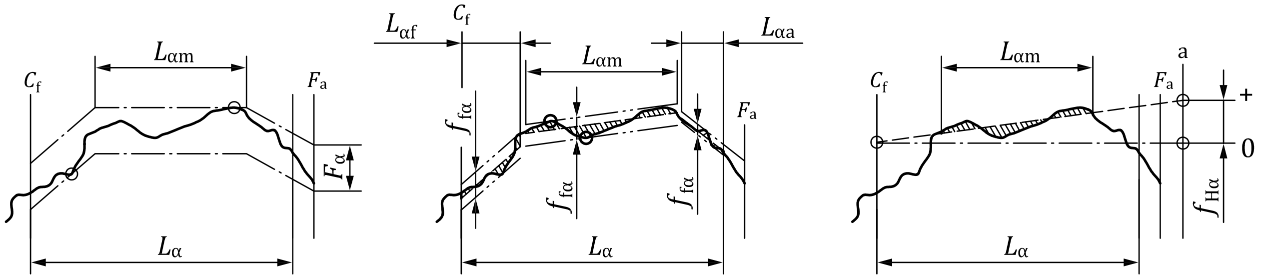
A.2.2 Profile form deviation, $f_{f\alpha}$

The profile form deviation, $f_{f\alpha}$, is the distance between two facsimiles of the regression lines which enclose the measured profile within the zone. For each zone, the form deviation is determined independently. For the area above the tip break, a plus material condition is included in the adjacent zone [see Figure A.2 b)].

NOTE The facsimiles of the regression line are kept parallel to the regression line.



a) Total profile deviation b) Profile form deviation c) Profile slope deviation

Key

————————	measured profile
—·—·—·—·—	facsimile of design profile
— — — — — — —	mean profile line
—··—··—··—	facsimile of mean profile line

Points on line of action

C_f profile control

F_a tip form

a tip

Figure A.2 — Zone-based evaluation for profile with tip and root modifications

A.2.3 Total profile deviation, F_α

The total profile deviation, F_α, is the distance between two facsimiles of the design profile which envelop the actual profile as shown in Figure A.2 a). Outside the evaluation range at the tip, excess material shall be taken into account.

NOTE 1 The facsimiles of the design profile are kept parallel to the design profile.

NOTE 2 It is common practice to restrict evaluation to the middle zone or to omit F_α completely.

A.3 Zone-based helix tolerance evaluation

For the determination of the slope and form deviation, a regression calculation is necessary. In the case of end relief, each zone is considered separately. The areas close to the faces are denoted with I and II (see Figure A.3).

For the calculation of the regression lines only the zones $L_{\beta I}$, $L_{\beta m}$, and $L_{\beta II}$ are used. The areas between the zones are only considered for the plus material condition for form and total deviation. The length of these areas shall be defined and cannot be zero (except when there is a tangential transition). The regression is calculated on the deviations from the design helix according to the sum of the least squares (Gauss). In most cases, a linear regression is used.

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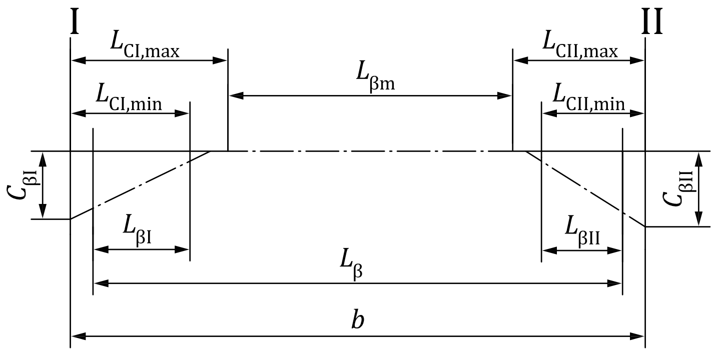

Key

I	datum face
II	non-datum face
$C_{\beta I}$	amount of end relief
$C_{\beta II}$	amount of end relief
$L_{CI,max}$	maximum length of end relief
$L_{CI,min}$	minimum length of end relief
$L_{CII,max}$	maximum length of end relief
$L_{CII,min}$	minimum length of end relief
$L_{\beta I}$	end relief zone
$L_{\beta m}$	middle helix zone
$L_{\beta II}$	end relief zone

Figure A.3 — Regression zones for a helix with relief at both ends

A.3.1 Helix slope deviation, $f_{H\beta}$

For the helix slope deviation, $f_{H\beta}$, the regression line of the middle zone shall be extrapolated to the whole facewidth, b [see Figure A.4 c)].

A.3.2 Helix form deviation, $f_{f\beta}$

The helix form deviation, $f_{f\beta}$, is the distance between two facsimiles of the regression line which enclose the measured helix within the zone. For each zone the form deviation is determined independently [see Figure A.4 b)]. For the area between the zones and at the ends, any plus material shall be included in the analysis.

NOTE The facsimiles of the regression line are kept parallel to the regression line.

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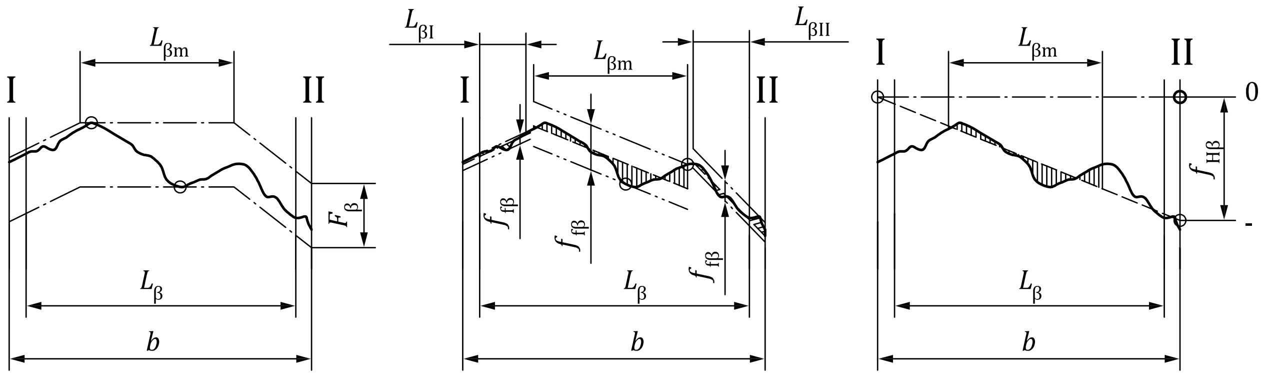
A.3.3 Total helix deviation, F_β

The total helix deviation, F_β, is the distance between two facsimiles of the design helix which envelop the actual helix [see Figure A.4 a)]. Outside the evaluation range, L_β, at the ends of the flank, excess material shall be taken into account.

NOTE 1 The facsimiles of the design helix are kept parallel to the design helix.

NOTE 2 It is common practice to restrict evaluation to the middle zone or to omit F_β completely.



a) Total helix deviation b) Helix form deviation c) Helix slope deviation

Key

————————	measured helix	$L_{\beta I}$	end relief zone (datum face)
—·—·—·—·—	facsimile of design helix	$L_{\beta II}$	end relief zone (non-datum face)
— — — — — — —	mean helix line	$L_{\beta m}$	middle helix zone
—··—··—··—	facsimile of mean helix line		

Figure A.4 — Zone-based evaluation for a helix with end modifications

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Annex B
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Evaluation of profile and helix deviations using the second order analysis method

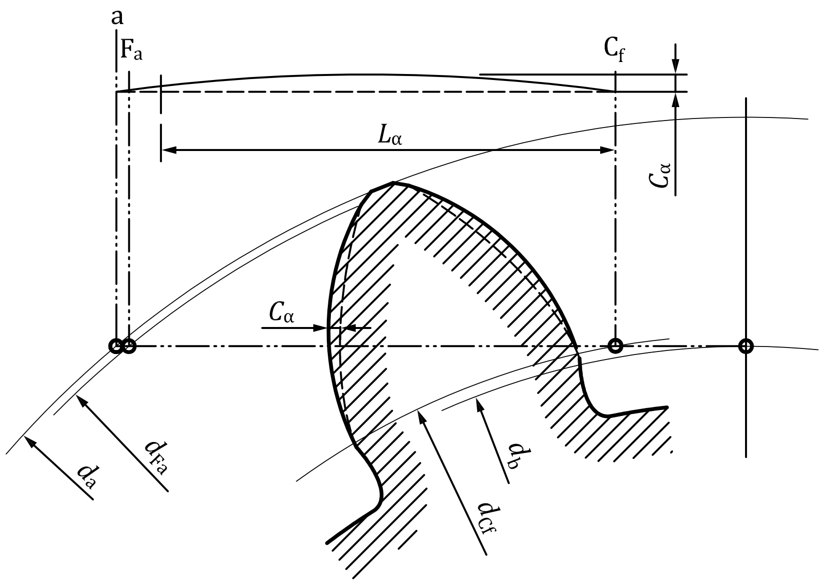
B.1 Purpose

This annex applies to gears with either a crowned profile (sometimes called barrelling) or a crowned helix, or to gears with both. A second order best fit is applied to the deviations from the unmodified profile or the unmodified helix. The standard flank tolerance classes from Clause 5 may be used with this method of analysis.

NOTE Clauses 3 and 4 use linear analysis of the deviations from the design profile and the design helix rather than a second order fit. The result of the linear analysis is referred to as a mean profile (or helix) **line** even though it has the same shape as the design profile (or helix), which can be a curve. The result of the second order analysis as presented in this annex is always referred to as a **curve**.

B.2 Second order profile analysis

Profile crowning is a commonly used and effective profile modification for some applications. Crowning modifications are generally defined by a single parabolic curve (see Figure B.1). The calculation of the parabola is executed within L_α, but for the evaluation of $f_{H\alpha}$ and C_α, the parabola is extrapolated to the tip diameter for unsegmented designs or to the end of the segment when analysed by zones.



Key

– – – – – – – – involute

———————— crowned profile

Figure B.1 — Profile crowning

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B.2.1 Mean second order profile curve

The mean second order profile curve is a curve created by mathematically fitting a second order curve to the measured profile trace, within the profile evaluation length, L_α, by the least squares method.

NOTE This curve is the basis of the determination of $f_{f\alpha}$, $f_{H\alpha}$ and C_α.

B.2.2 Profile form deviation, $f_{f\alpha}$

The profile form deviation, $f_{f\alpha}$, is the distance between two facsimiles of the mean second order profile curve, which are each placed with constant separation from the mean second order profile curve, so as to enclose the measured profile over the profile evaluation length, L_α [see 3.3.10 and Figure B.2 a)]. See 4.4.8.2 for plus material conditions.

B.2.3 Profile slope deviation, $f_{H\alpha}$

The profile slope deviation, $f_{H\alpha}$, is the displacement of a line struck through the points where the extrapolated mean second order profile curve intersects the profile control diameter and the tip diameter [see Figure B.2 b)].

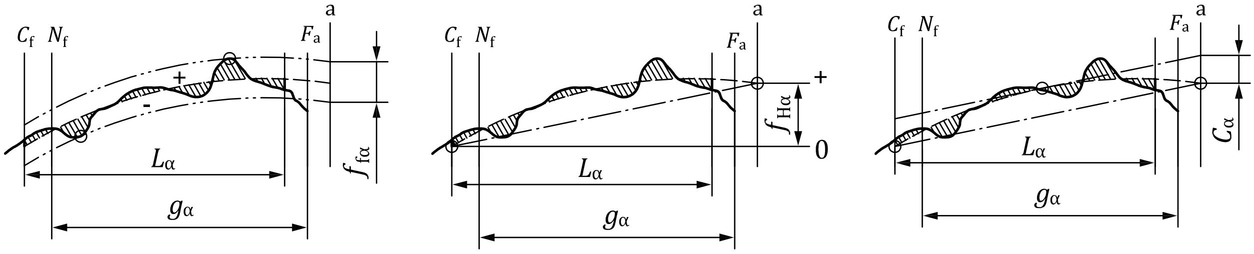
The algebraic sign of profile slope deviation, $f_{H\alpha}$, using the second order method is determined in the same manner as given in 4.4.8.2.

If there is a design profile slope deviation, $C_{H\alpha}$, the initially calculated $f_{H\alpha C}$ is used to determine the profile slope deviation according to Formula (B.1):

$$f_{H\alpha} = f_{H\alpha C} - C_{H\alpha} \tag{B.1}$$

B.2.4 Profile crowning, C_α

The profile crowning, C_α, is the distance, in the direction of recorded deviations, between the chord to the extrapolated mean second order profile curve where it intersects the profile control diameter and the tip diameter and a parallel line which is tangent to the mean second order profile curve [see Figure B.2 c)].



Key

		Points on line of action		
————————	measured profile	C_f	profile control
— — — — — — —	mean second order profile curve	N_f	start of active profile
—..—..—..—	facsimile of mean second order profile curve	F_a	tip form
—.—.—.—.—	chord of mean second order profile curve	a	tip

Figure B.2 — Second order profile deviations

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B.3 Second order helix analysis

Similar to profile crowning, helix crowning is a commonly used helix modification. This modification is generally defined by a single parabolic curve that increases the curvature of the helix and crests at the middle of the helix evaluation range, L_β. The calculation of the parabola is executed within L_β, but for the evaluation of $f_{H\beta}$ and C_β, the parabola is extrapolated to the full facewidth, *b,* for unsegmented designs, or to the end of the segment when analysed by zones.

B.3.1 Mean second order helix curve

The mean second order helix curve is a curve that is created by mathematically fitting a second order curve to the measured helix trace, within the helix evaluation range, L_β, by the least squares method.

NOTE This curve is the basis of the determination of $f_{f\beta}$, $f_{H\beta}$ and C_β.

B.3.2 Helix form deviation, $f_{f\beta}$

The helix form deviation, $f_{f\beta}$, is the distance between two facsimiles of the mean second order helix curve, which are each placed with constant separation from the mean second order helix curve, so as to enclose the measured helix trace over the helix evaluation range, L_β [see Figure B.3 a)]. See 4.4.8.4 for plus material conditions.

B.3.3 Helix slope deviation, $f_{H\beta}$

The helix slope deviation, $f_{H\beta}$, is the displacement of a line struck through the points where the mean second order helix curve intersects the end points of the facewidth, *b* [see Figure B.3 b)].

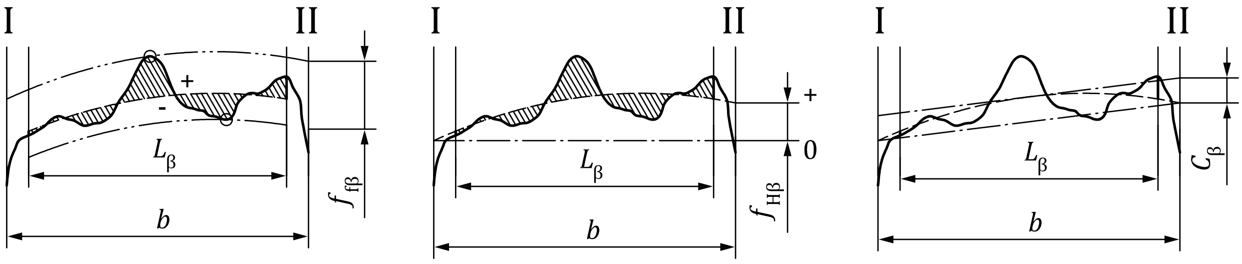
The algebraic signs of helix slope deviation, $f_{H\beta}$, using the second order method are determined in the same manner as in 4.4.8.4.

If there is a design helix slope deviation, $C_{H\beta}$, then the initially calculated $f_{H\beta C}$ is used to determine the helix slope deviation according to Formula (B.2):

$$f_{H\beta} = f_{H\beta C} - C_{H\beta} \tag{B.2}$$

B.3.4 Helix crowning, C_β

The helix crowning, C_β, is the distance, in the direction of recorded deviations, between the helix slope line and a parallel line which is tangent to the mean second order helix curve [see Figure B.3 c)].



a) Helix form deviation **b) Helix slope deviation** **c) Helix crowning**

Key

———— measured helix

— — — — mean second order helix curve

—··—··— facsimile of mean second order helix curve

Figure B.3 — Second order helix deviations

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Annex C
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Profile and helix data filtering

C.1 Purpose

Profile and helix measurement data are usually conditioned by low-pass filtering prior to analysis procedures. The selected filtering method and cutoff wavelength influences analysis results. This annex provides descriptions of filtering practices.

C.2 Filtering

Measurements include variations of many different wavelengths or frequencies. The exclusion of certain portions of the measurement data frequency spectrum is called filtering. A filter that excludes short wavelength (high frequency) data is called a low-pass filter. A filter that excludes long wavelength (low frequency) data is called a high-pass filter. A filter that excludes the shortest and longest wavelengths (highest and lowest frequencies), thereby leaving only medium wavelength (medium frequency) data, is called a bandpass filter. For gear metrology purposes, a low-pass filter is usually applied to remove the influences of high-frequency surface finish conditions from the observations of total, form and slope deviations of profile and helix. Several types of filtering are normally present in the gear measuring system.

C.3 Mechanical filtering

Mechanical filtering limits the profile and helix measurement data gathered to longer wavelength values and is thus a low-pass type filter. Mechanical filtering occurs as the geometry of the probe (i.e. tip radius) bridges and thereby suppresses the shorter wavelength variations. Another relevant source of mechanical low-pass filtering is the inertial mass of the moving parts of the probing system.

In applications that require inclusion of higher frequency data, smaller probe tip radii can be specified. Since gear profile and helix data are normally subjected to intentional low-pass filtering, this is rarely required. Evaluation of gear surface finish is best accomplished with specialized surface finish instruments, rather than profile or helix measurement instruments.

C.4 Electrical filtering

Electrical filtering that limits the measurement data gathered to longer wavelengths (lower frequency) values is a low-pass type filter. During electrical filtering, the measurement data signal passes from the probe head through an electrical filtering (RC) circuit and finally on to the data analysis and output devices.

Electrical filtering circuits for profile and helix data are designed to accomplish the elimination of high frequency measurement data at a specified wavelength called the cutoff. All data at frequencies significantly higher than the cutoff are eliminated. High-frequency measurement data that are near but not exactly at the cutoff frequency are filtered proportionally according to their proximity to the cutoff wavelength.

An unfortunate effect of RC electrical filtering is a phase shifting of data that can influence the analysis of measurement results.

Electrical filtering is most commonly encountered on older instruments; newer instruments employ mathematical filtering. Electrical filtering is an acceptable practice, provided its limitations are understood.

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C.5 Mathematical filtering

Mathematical filtering requires that measurement data first be converted from analogue to digital to permit processing by a digital computer. There are many mathematical filters available today. One common filter emulates the characteristics of electrical filters (with or without the phase shifting characteristic of RC circuits). Another common filter employs Gaussian mathematics.

The transmission characteristics of a phase correct Gaussian filter are such that 50 % of the amplitude of a sinusoidal waveform with a wavelength equal to the long-wavelength cutoff will be transmitted. Other frequencies are passed in an amount according to their proximity to the cutoff. When a phase correct Gaussian filter is used, irregularities are reduced and phase shift is eliminated.

Based upon sine wave amplitude transmission characteristics and compliance with ISO standards, use of the digital Gaussian 50 % filter is required (see 4.4.6).

It is also advantageous to be able to view the measurement data with different (or no) mathematical filtering applied.

C.6 Cutoff selection

Standard profile and helix data cutoff values for use in this part of ISO 1328 are specified in 4.4.6.

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Annex D
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Sector pitch deviation

D.1 Purpose

This annex provides the definition, measurement practices, recommended tolerances, and guidance for application of sector pitch deviation.

D.2 Sector pitch deviation, F_{pk}, $F_{pz/8}$

The sector pitch deviation, F_{pk}, is the largest algebraic difference between the individual cumulative pitch deviation (index deviation) values for a specified flank within any sector of k pitches. In the specific case where k is one eighth of the number of teeth, z, it is named $F_{pz/8}$.

NOTE 1 Unless otherwise specified, k is limited to one eighth of the number of teeth. For segment gears, the number of teeth, z, is that for a full gear, and not the number of teeth in the segment gear.

NOTE 2 When a specific number of teeth is specified, that number appears in the symbol in place of k; i.e. if sectors of four teeth are used, the symbol is F_{p4}.

NOTE 3 When $F_{pz/8}$ is specified, then

$$k \approx \frac{z}{8} \quad \text{(D.1)}$$

where

k is the number of pitches in the sector; it is rounded to the nearest integer of pitches;

z is the number of teeth in the gear.

The smallest useful value of k is 2. Parameter $F_{pz/8}$ is only applicable to gears with 12 or more teeth.

Distinction is made as to the algebraic sign of this reading. Thus, a condition wherein the distance between the two teeth comprising the sector pitch deviation is shorter than the theoretical distance is considered a minus (-) deviation. A condition wherein the distance between the two teeth comprising the sector pitch deviation is longer than the theoretical distance is considered a plus (+) deviation.

The measurement direction for sector pitch deviation is along the arc of the measurement diameter circle, d_M, within the transverse plane.

D.3 Measurement practice

Gear tooth position data gathered by either a pitch comparator (two-probe) device or an indexing (single-probe) device may be used to determine sector pitch deviation. In either case, individual cumulative pitch deviation (index deviation) values shall be found first. Determination of the sector pitch deviation, F_{pk}, requires the algebraic difference of the most positive individual cumulative pitch deviation (index deviation) value and the most negative individual cumulative pitch deviation (index deviation) value within every group of k pitches (k + 1 adjacent teeth), as defined in D.2. The sector pitch deviation, F_{pk}, is the largest of these values. There are as many groups of k pitches as there are teeth.

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D.4 Comparison to similar parameters

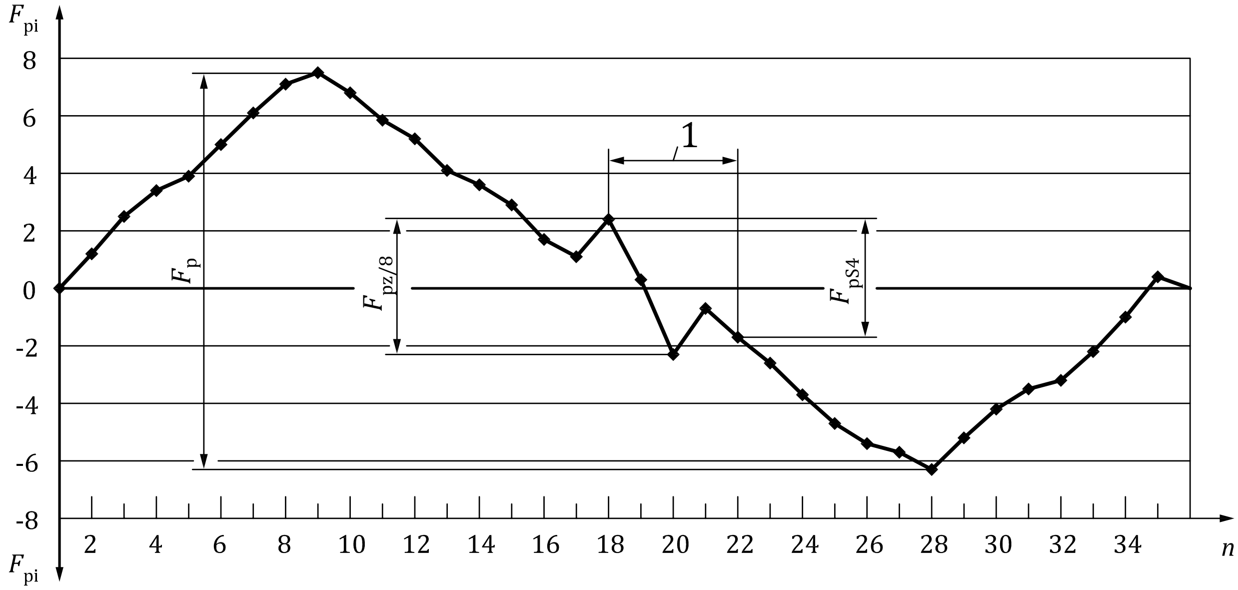
It is important to understand that parameter F_{pk} is not equivalent to certain other similar parameters, such as pitch span deviation F_{pSk}. Pitch span deviation is equal to the algebraic difference between the first and last values of the individual cumulative pitch deviation (index deviation) in a sector of k pitches.

In both cases, a window of k spaces is used. For F_{pk}, z windows of length k are used and (maximum reading minus minimum reading) is determined for each window for all values inside the window.

For F_{pSk}, the number of windows is equal to the nearest integer of z/k. For each interval, only the first and last values are considered to determine the difference.

NOTE The tolerance for F_{pSk} is not specified in this part of ISO 1328.

An example of the differences between these analysis methods is provided by Figure D.1. That Figure shows the individual cumulative pitch deviation (index deviation) data for a gear with 35 teeth, thus for $F_{pz/8}$, the value of k is equal to 4. In this example, the value of sector pitch deviation, $F_{pz/8}$, is 4,7 occurring between teeth 18 and 20, which are contained within a sector of 4 pitches. The value of pitch span deviation, F_{pS4}, is 4,1 occurring from teeth 18 and 22, which are 4 pitches apart. In this example, $F_{pz/8}$ and F_{pS4} occur in the same sector; this is not always the case.



Key

1 4 pitch sector with largest tooth deviation

n tooth number

F_p total cumulative pitch deviation

$F_{pz/8}$ sector pitch deviation ($z/8 \approx 4$)

F_{pS4} pitch span deviation, 4 teeth

Figure D.1 — Sector pitch deviation and pitch span deviation

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D.5 Tolerance, sector pitch deviation, F_{pkT}

A recommended tolerance for sector pitch deviation, F_{pkT}, is calculated according to Formula (D.2):

$$F_{\text{pkT}} = f_{\text{pT}} + \frac{4k}{z}\left(0{,}001d + 0{,}55\sqrt{d} + 0{,}3m_{\text{n}} + 7\right)\left(\sqrt{2}\right)^{A-5} \tag{D.2}$$

where

F_{pkT} is the tolerance, sector pitch;

f_{pT} is the tolerance, single pitch, for the tolerance class A.

A recommended range of application for sector pitch tolerance follows the same restrictions as those specified for total cumulative pitch tolerance, F_{pT}.

For the specific case of $F_{\text{pz/8}}$, Formula (D.2) may be simplified to:

$$F_{\text{pz/8T}} = \frac{f_{\text{pT}} + F_{\text{pT}}}{2} \tag{D.3}$$

D.6 Guidance to application

Unless otherwise specified, the measurement of sector pitch deviation is not mandatory. Information pertaining to this parameter is therefore not included in (the main body of) this part of ISO 1328.

However, when agreed between the manufacturer and purchaser, the method may be used. If differences between individual cumulative pitch deviations (index deviations) over relatively small numbers of pitches are too large, substantial acceleration forces can be generated when the gear is in service, especially for high speed gears, where dynamic loads can be considerable.

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Annex E
(normative)

Allowable values of runout

E.1 Purpose

This annex provides the tolerance formula and range of application.

E.2 Individual radial measurement, r_i

The individual radial measurement, r_i, is the radial distance from the gear axis to the centre or other defined location of a probe (ball, cylinder or anvil), which is placed successively in each tooth space. During each check, the probe contacts both the right and left flanks at approximately midtooth-depth. The runout may also be determined by using the points from the pitch measurement (see E.5 and Figure E.2).

NOTE 1 There are as many values for r_i as there are tooth spaces.

NOTE 2 The results from a physical measurement usually give slightly different results from those calculated from the pitch measurement.

When a specific ball diameter for runout measurement is required, the contact diameter for this ball shall be used for pitch measurements, if these measurements will be used for calculation of runout. Otherwise, the measurement diameter, d_M, shall be used.

E.3 Runout, F_r

The value of the runout, F_r, of the gear is the difference between the maximum and the minimum individual radial measurement, r_i. Figure E.1 shows an example of a runout diagram, in which the eccentricity is a portion of the runout (see ISO/TR 10064-2).

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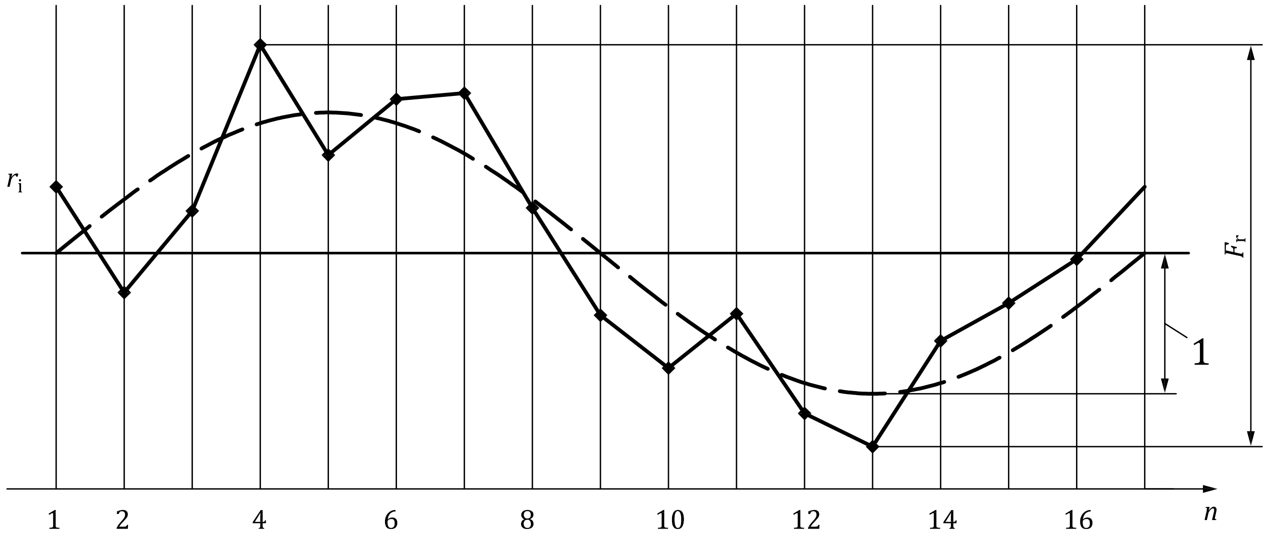

Key

1 eccentricity

n tooth space number

Figure E.1 — Runout diagram of a gear with 16 teeth

E.4 Recommended formula for runout tolerance, F_{rT}

Runout tolerance, F_{rT}, shall be calculated using Formula (E.1):

$$F_{rT} = 0,9F_{pT} = (0,9)\left(0,002d + 0,55\sqrt{d} + 0,7m_n + 12\right)\left(\sqrt{2}\right)^{A-5} \tag{E.1}$$

where the range of application is restricted as follows:

tolerance classes 1 to 11

$5 \leq z \leq 1\,000$

$5 \text{ mm} \leq d \leq 15\,000 \text{ mm}$

$0,5 \text{ mm} \leq m_n \leq 70 \text{ mm}$

E.5 Calculation of runout from pitch measurements

From the probings at the measurement diameter, the positions of the left and right flanks are known. In a transverse plane, involutes are created in the tooth space at a distance from the measured points that is equal to the radius of the ball divided by the cosine of the base helix angle. The distance is measured in a direction along a tangent to the base circle. The intersection of the two involutes for each tooth space gives the approximate radial position of the centre of the test ball. These positions may also be used for the determination of dimension over balls. The results may deviate slightly from those actually made with a ball in two flank contact, due to differences in contact location and surface irregularities. See Figure E.2, which shows a simplified example for a spur gear.

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E.6 Guidance to application

Unless otherwise specified, the measurement of runout is not mandatory. Information pertaining to this parameter is, therefore, not included in (the main body of) this part of ISO 1328. However, when agreed between the manufacturer and purchaser, the method may be used.

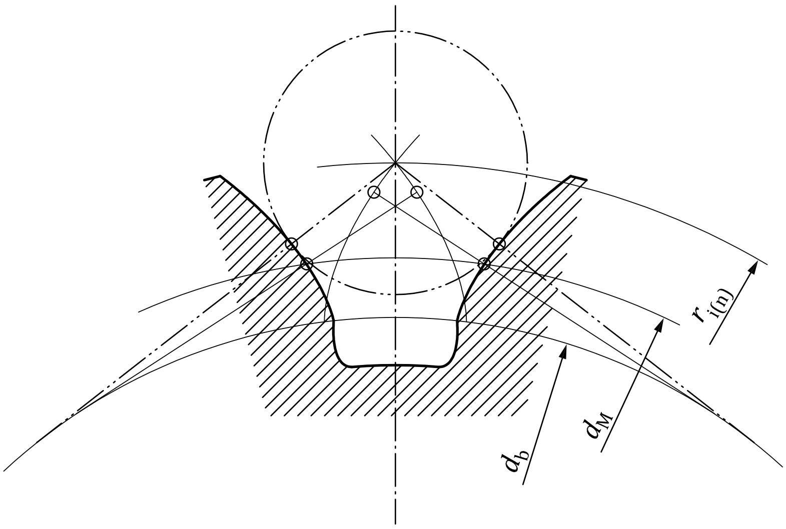

Figure E.2 — Runout from pitch measurement

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Annex F
(informative)

Single flank composite testing

F.1 Purpose

F.1.1 General

This annex is provided as a discussion of gear transmission error (deviation) and to give a default tolerance value for tooth mesh single flank composite deviation, $f_{is(design)}$. Transmission error is the deviation of the angular position of the driven gear, for a given angular position of the driving gear, from the position that the driven gear would occupy if the gears were geometrically perfect.

Single flank inspection is a method used to measure transmission error. It is typically conducted on instruments that run gears together as a pair. At times, it is also conducted with a product gear running against a master gear, to measure the individual gear contribution to the transmission error. These tests are normally conducted at very light torque loads in order to avoid deflections of the typical production test machines that can influence the measured results. When it is necessary to test under heavy loads, such as in the actual application, this should be done in the actual gear box or a special very rigid test box, but this is beyond the scope of this annex.

With single flank testing, gears roll together at their specified centre distance and alignment with only one set of flanks in contact. The gear pair should have backlash. Because single flank testing of gears simulates operation in their application, deviations of a gear pair detected by this test are useful to control gear functional characteristics. Nicks and burrs may also be detected.

Single flank testing will show results for no-load total transmission error and tooth-to-tooth error. Tooth-to-tooth transmission error is the parameter of importance when looking for smoothness of motion or control of noise and vibration. When considering tolerances for no-load total transmission error, accumulated pitch error is the prime source. When analysing tooth-to-tooth error, conjugacy of mating teeth (matching of involute shape) is the prime source.

There are two groups of gear types to be considered when establishing tolerances for tooth-to-tooth no-load transmission error: unmodified tooth shapes and modified tooth shapes.

F.1.2 Unmodified tooth shapes

Unmodified tooth shapes are used for gears in many applications such as home appliances, power hand tools, automotive accessory drives and many others, which run at very low loads. For low loads, the more conjugate the teeth are, the smoother they run, and they will generate less noise and vibration. Therefore, any result less than the tolerance value is acceptable.

F.1.3 Modified tooth shapes

Modified tooth shapes (profile crowning, tip relief, profile slope, etc.) may show relatively high tooth-to-tooth transmission error. This is because they are tested at light loads, while the teeth have been designed to be conjugate only at a specified high load condition. They, therefore, are not conjugate at low inspection loads. If the tooth-to-tooth transmission error is much less than expected, that would not be good. Therefore, in the modified situation, there should be maximum and minimum tolerances.

There are two alternative methods to determine these maximum and minimum tolerances:

a) based on experience in actual applications;

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b) through the use of tooth contact analysis software programs that determine tooth shape and predicted transmission error curves. These programs analyse the tooth shapes as they run under load and also account for housing and shaft deflections. They then predict the tooth-to-tooth transmission error at various load levels and one would expect to know what it should look like under light loads in a single flank tester.

F.1.4 Method A

The design and manufacture determination of single flank composite mean tooth mesh component value, and its variability, is developed using application experience or load capacity testing, or both, to determine the required values. These values are regardless of quality class.

F.1.5 Method B

The peak-to-peak amplitude of the short-term component (high-pass filtered) of the single flank composite deviation is used to determine the tooth mesh component. The highest peak-to-peak amplitude shall not be greater than f_{isTmax} and the lowest peak-to-peak amplitude shall not be smaller than f_{isTmin}. The peak-to-peak amplitude is the difference between the highest point and the lowest point of the motion curve within one pitch of the gear set being measured.

The maximum and minimum values of the single flank composite tolerance, tooth mesh component, f_{isT}, for a gear pair shall be calculated according to Formulae (F.1) and (F.2), or (F.1) and (F.3), in micrometres.

$$f_{isT,max} = f_{is(design)} + \left(0{,}375\, m_n + 5{,}0\right)\left(\sqrt{2}\right)^{(A-5)} \tag{F.1}$$

The value of f_{isTmin} is the larger one of:

$$f_{isT,min} = f_{is(design)} - \left(0{,}375\, m_n + 5{,}0\right)\left(\sqrt{2}\right)^{(A-5)}, \text{or} \tag{F.2}$$

$$f_{isT,min} = 0 \tag{F.3}$$

The range of application is restricted as follows:

flank tolerance classes 1 to 11

$1{,}0 \text{ mm} \le m_n \le 50 \text{ mm}$

$5 \le z \le 400$

$5 \text{ mm} \le d \le 2\,500 \text{ mm}$

If the measuring instrument reads in units of angle, the conversion to micrometres should be done at the reference diameter, d.

$$f_{isT} \text{ (micro radians)} = 2\,000 \times f_{isT} \text{ (micrometres)}/d \text{ (mm)} \tag{F.4}$$

The design value for tooth mesh component single flank composite deviation, $f_{is(design)}$, for Formulae (F.1) and (F.2), should be determined with an analysis for the application design and testing conditions. Consideration should be given in selecting the design value such that it includes influences, such as mounting variation, variability of flank form and application operating loads. See F.2 for additional information.

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F.1.6 Single flank composite tolerance, total, F_{isT}

Single flank composite tolerance, total, F_{isT}, shall be calculated according to Formula (F.5):

$$F_{isT} = F_{pT} + f_{isT,max} \tag{F.5}$$

where the range of application is restricted as follows, if F_{isT} is specified:

flank tolerance grades 1 to 11

$1{,}0 \text{ mm} \le m_n \le 50 \text{ mm}$

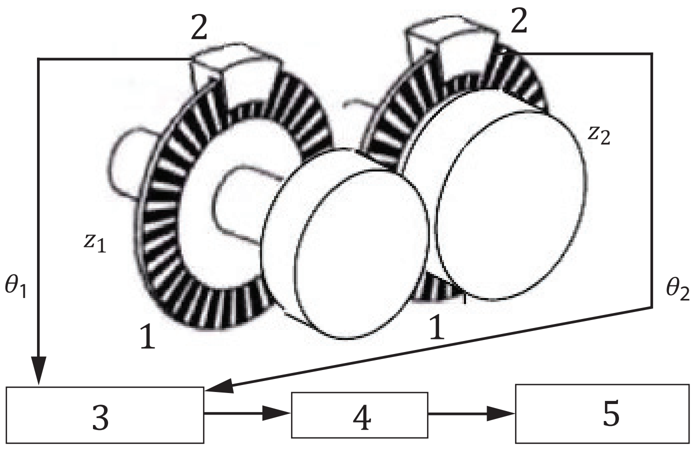
$5 \le z \le 400$

$5 \text{ mm} \le d \le 2\,500 \text{ mm}$

F.2 Structure of the tester and obtained data

Figure F.1 shows the schematic view of the single flank tester. The rotary angles θ_1 and θ_2 are detected by the rotary angle sensor, such as an encoder, attached to the pinion and gear shaft. The transmission error, θ_e, of the gear pair is calculated by Formula (F.6):

$$\theta_e = \theta_2 - \left(\frac{z_1}{z_2}\right)\theta_1 \tag{F.6}$$



Key

1 rotary encoder

2 reading device

3 calculation of transmission error

4 filtering

5 fourier transform

Figure F.1 — Schematic view of single flank tester

The recommended minimum number of measurement points to evaluate single flank parameter is 30 points per tooth. Then, the data are filtered and Fourier transformed. The example of transmission wave form shown in Figure F.2 has the complex shape caused by the cumulative deviation of pinion and gear.

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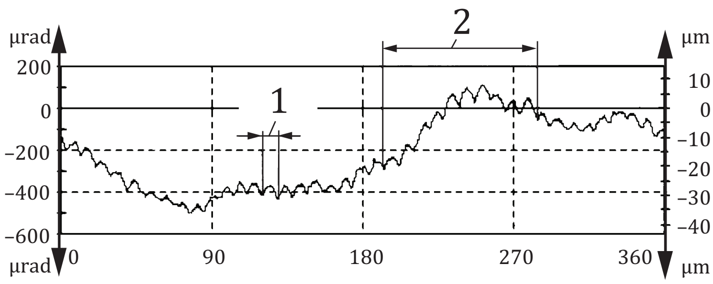


Key

1 tooth pitch

2 one revolution of pinion

Figure F.2 — An example of transmission error

The small waves within one pitch are caused by tooth form deviation. Figure F.3 shows the high-pass filtered deviation waves with the tooth pitch period corresponding to the variety of tooth form deviations. Additionally, the minimum and maximum value of the single flank composite tooth mesh component, $f_{is\ min}$ and $f_{is\ max}$, are indicated. Figure F.4 shows the Fourier transformed deviations. Sharp peaks can be seen at the mesh frequency and at the second order mesh frequency.

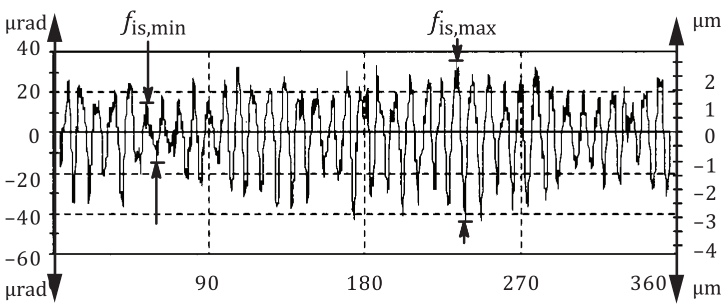
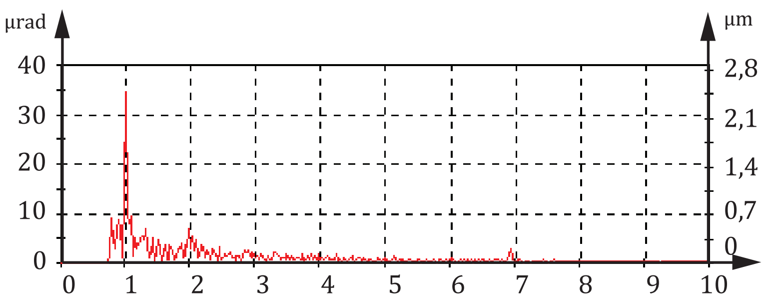


Figure F.3 — High-pass filtered single flank composite deviations



a) Order of tooth mesh frequency-linear amplitude

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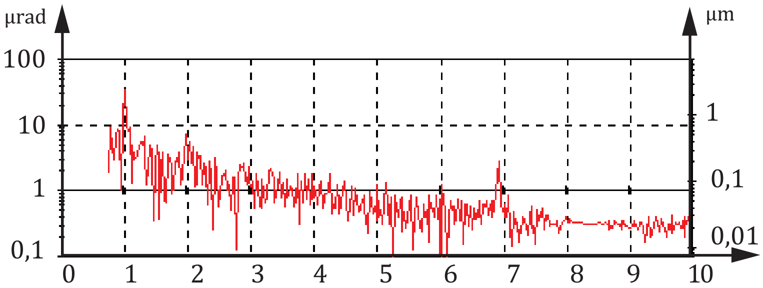

b) Order of tooth mesh frequency-log amplitude

Figure F.4 — Fourier transformed single flank composite deviations

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Annex G
(informative)

Adjacent pitch difference, f_u

G.1 Adjacent pitch difference definitions

G.1.1 Individual adjacent pitch difference, f_{ui}

The individual adjacent pitch difference, f_{ui} (no algebraic sign), is the difference between the actual measured values of two consecutive individual single pitches of right or left flanks. It is equal to the difference between the individual single pitch deviations of two consecutive pitches (see Figure G.1).

$$f_{ui(n)} = \left| f_{pi(n)} - f_{pi(n-1)} \right| \tag{G.1}$$

G.1.2 Adjacent pitch difference, f_u

The adjacent pitch difference, f_u, is the maximum of the values of individual adjacent pitch difference, f_{ui}.

G.2 Tolerance value

The adjacent pitch difference tolerance, f_{uT}, shall be calculated using Formula (G.2):

$$f_{uT} = \sqrt{2} f_{pT} \tag{G.2}$$

G.3 Guidance to application

The use of adjacent pitch difference shall be agreed upon between the manufacturer and purchaser.

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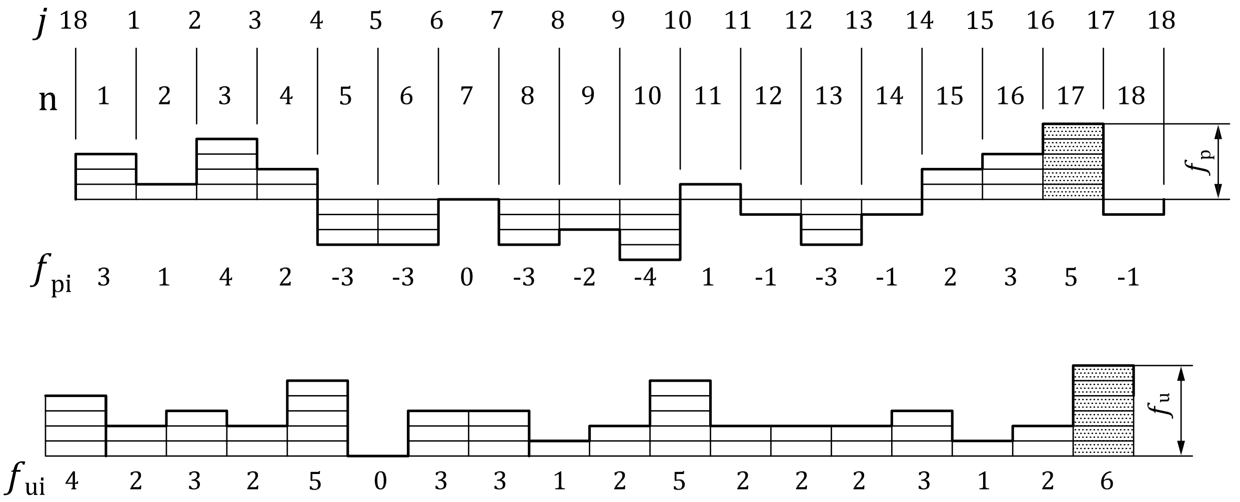

Key

f_{pi} individual single pitch deviation

f_{ui} individual adjacent pitch difference

j flank number

n pitch number

Figure G.1 — Adjacent pitch difference

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