INTERNATIONAL STANDARD

ISO 17485

First edition
2006-06-15

Bevel gears — ISO system of accuracy

Engrenages coniques — Système ISO d'exactitude

Reference number
ISO 17485:2006(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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 17485 was prepared by Technical Committee ISO/TC 60, *Gears*.

Introduction

The measurement and tolerance specification of bevel gears are very complex subjects that were in need of international standardization. For these and other reasons, ISO/TC 60 approved the project based on a proposed document, ANSI/AGMA 2009-B01, *Bevel Gear Classification, Tolerances, and Measuring Methods*.

At an early stage it was decided to develop two documents: this International Standard, with accuracy grades and definitions, and a separate Technical Report, ISO/TR 10064-6, containing inspection practice and measuring methods. These practices and measuring methods include topics such as manufacturing considerations, CMM measurements, contact pattern checking, and advanced topics such as bevel gear flank form analysis.

Prior to the development of this International Standard, the accuracy grades described in ISO 1328, for cylindrical gears, were often used for bevel gears. However, this use was not always consistent with the specific requirements and general practices followed within the bevel gear industry. This International Standard contains items that are distinctly different from ISO 1328-1:1995:

— the definitions, tolerance diameter and measuring directions are specifically for bevel gears;

— accuracy grade tolerances are based on equations and not on tables;

— there is approximately one grade difference in tolerance level between bevel and cylindrical gears, similar to that used by the DIN system of tolerances.

The use of the definitions and accuracy grades within this International Standard should improve the consistent application of bevel gear geometrical tolerances for the general benefit of industry.

Bevel gears — ISO system of accuracy

1 Scope

This International Standard establishes a classification system that can be used to communicate geometrical accuracy specifications of unassembled bevel gears, hypoid gears, and gear pairs. It defines gear tooth accuracy terms and specifies the structure of the gear accuracy grade system and allowable values.

This International Standard provides the gear manufacturer and the gear buyer with a mutually advantageous reference for uniform tolerances. Ten accuracy grades are defined, numbered 2 to 11 in order of decreasing precision. Equations for tolerances and their ranges of validity are provided in 5.4 for the defined accuracy of gearing. In general, these tolerances cover the following ranges:

$1,0 \text{ mm} \leqslant m_{mn} \leqslant 50 \text{ mm}$

$5 \leqslant z \leqslant 400$

$5 \text{ mm} \leqslant d_T \leqslant 2\,500 \text{ mm}$

where

d_T is the tolerance diameter;

m_{mn} is the mean normal module;

z is the number of teeth.

See Clause 6 for required and optional measuring methods. As tolerances are calculated from the actual dimensions of a bevel gear, tolerance tables are not provided. In order to provide an overview, example values of tolerances and graphs are given in Annex A.

This International Standard does not apply to enclosed gear unit assemblies, including speed reducers or increasers, gear motors, shaft mounted reducers, high speed units, or other enclosed gear units manufactured for a given power, speed, ratio or application.

Gear design is beyond the scope of this International Standard. The use of the accuracy grades for the determination of gear performance requires extensive experience with specific applications. Therefore, the users of this International Standard are cautioned against the direct application of tolerance values to a projected performance of unassembled (loose) gears when they are assembled.

Tolerance values for gears outside the limits stated in this International Standard will need to be established by determining the specific application requirements. This could require the setting of a tolerance other than that calculated by the formulas in this International Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1122-1:1998, *Vocabulary of gear terms — Part 1: Definitions related to geometry*

ISO 23509[1)], *Bevel and hypoid gear geometry*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in ISO 1122-1, ISO 23509 and the following terms, definitions and symbols apply.

Some of the symbols and terminology contained in this document could differ from those used in other documents and standards. Users of this International Standard should assure themselves that they are using the symbols, terminology and definitions in the manner indicated herein.

3.1 Terms and definitions

3.1.1
index deviation
F_x
displacement of any tooth flank from its theoretical position, relative to a datum tooth flank

3.1.2
mean normal module
m_{mn}
ratio of the mean pitch diameter in millimetres to the number of teeth in a normal plane at the mean cone distance

$$m_{mn} = \frac{d_m}{z} \cos\beta_m = \frac{R_m}{R_e} m_{et} \cos\beta_m \qquad (1)$$

where

d_m is the mean pitch diameter,

z is the number of teeth,

β_m is the mean spiral angle,

R_m is the mean cone distance,

R_e is the outer cone distance, and

m_{et} is the outer transverse module

3.1.3
reference gear
gear of known accuracy that is designed specifically to mesh with the gear to be inspected for composite deviation and contact marking tests

1) To be published.

3.1.4
total runout deviation
F_r
difference between the maximum and minimum distance perpendicular to the pitch cone, of a probe (ball or cone) placed successively in each tooth space, with the probe contacting both the right and left flanks at the tolerance circle approximately mid tooth-depth

NOTE Tolerances are provided in 5.4.4.

3.1.5
tooth mesh component single-flank composite deviation
f_{is}
value of the greatest single-flank composite deviation over any one pitch (360°/z), after removal of the long-term component (sinusoidal effect of eccentricity), during a single-flank composite test, when the wheel is moved through one revolution

NOTE This International Standard specifies the tolerance direction for tooth mesh component single-flank composite deviation to be along the arc of the tolerance diameter circle in a transverse section. Tolerances are provided in 5.4.5.

3.1.6
total single-flank composite deviation
F_{is}
total deviation, measured from minimum to maximum, during a single-flank composite test, when the wheel is moved through one revolution

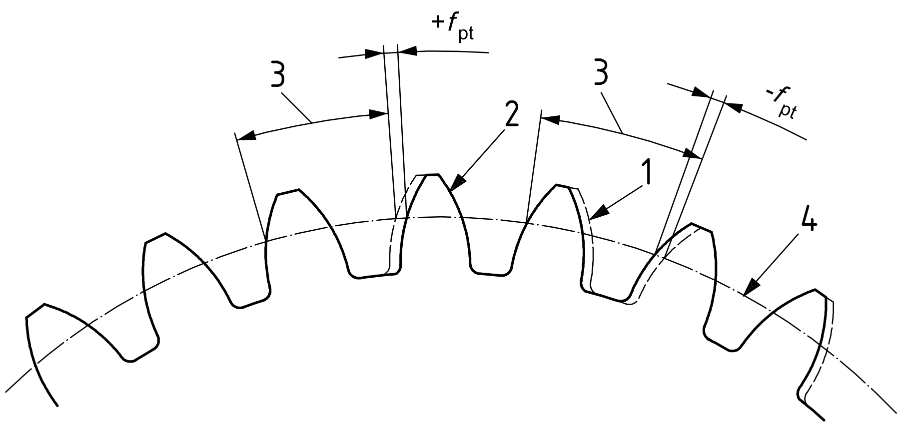
NOTE This International Standard specifies the tolerance direction for total single-flank composite deviation to be along the arc of the tolerance diameter circle in a transverse section. See Annex B. Tolerances are provided in 5.4.6.

3.1.7
single pitch deviation
f_{pt}
displacement of any tooth flank from its theoretical position relative to the corresponding flank of an adjacent tooth, measured by a probe from a point on a flank, to a point on the adjacent flank, on the same measurement circle

See Figure 1.

NOTE 1 Distinction is made as to the algebraic sign of the measured value. Thus, a condition wherein the actual tooth flank position was nearer to the adjacent tooth flank than the theoretical position would be considered a minus (−) deviation. A condition wherein the actual tooth flank position was farther from the adjacent tooth flank than the theoretical position would be considered a plus (+) deviation.

NOTE 2 This International Standard specifies the tolerance direction of measurement for single pitch deviation to be along the arc of the tolerance diameter circle in the transverse section. Tolerances are provided in 5.4.2.



Key

1 theoretical tooth flank position
2 actual tooth flank position
3 theoretical circular pitch
4 measurement circle

Figure 1 — Pitch deviations

3.1.8
tolerance diameter
d_T
diameter where the mean cone distance, R_m, and the midpoint of the working depth intersect

See Figure 2.

NOTE The midpoint of the mean working depth is one half the depth of engagement of the two gears at the mean cone distance. The value of d_T can be determined by Equations (2) or (3).

$$d_{T1} = d_{m1} + 2(0{,}5\, h_{mw} - h_{am2})\cos\delta_1 = d_{m1} + (h_{am1} - h_{am2})\cos\delta_1 \quad (2)$$

$$d_{T2} = d_{m2} - 2(0{,}5\, h_{mw} - h_{am2})\cos\delta_2 = d_{m2} + (h_{am2} - h_{am1})\cos\delta_2 \quad (3)$$

where

$d_{m1,\,2}$ is the mean pitch diameter (pinion, wheel);

h_{mw} is the mean working depth;

$h_{am1,\,2}$ is the mean addendum;

$\delta_{1,\,2}$ is the pitch angle (pinion, wheel).

These values can be obtained from manufacturing summary sheets or by calculations shown in ISO 10300 or in ISO 23509.

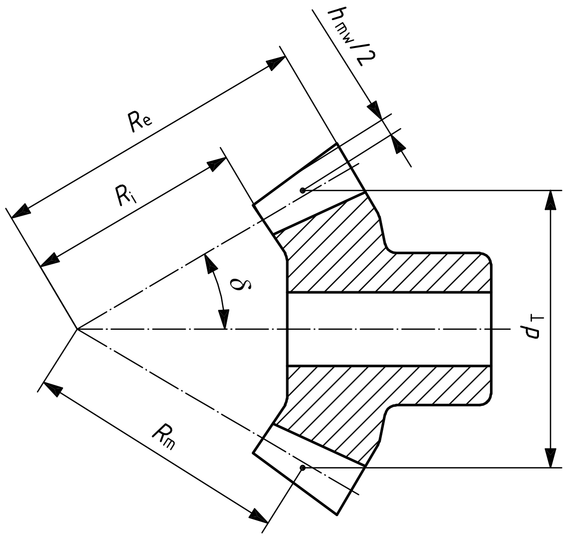
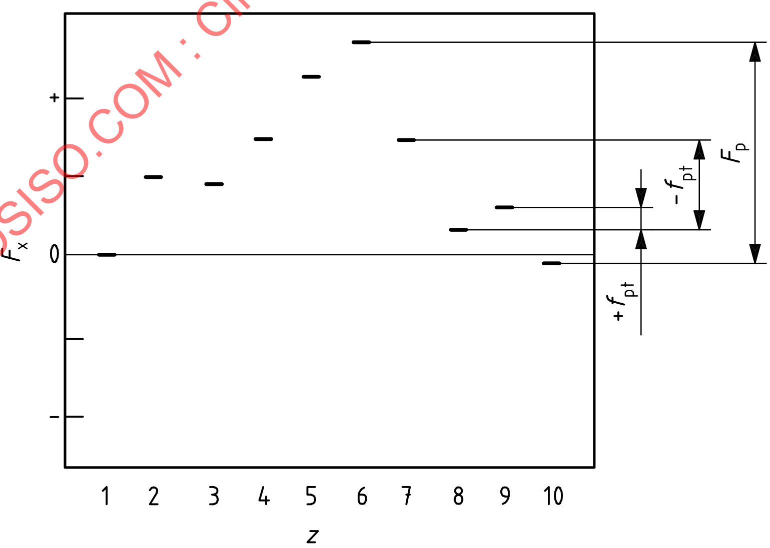


Figure 2 — Tolerance diameter

3.1.9
total cumulative pitch deviation
F_p
largest algebraic difference between any two index deviation values for a specified flank (left or right), without distinction as to the direction or algebraic sign of this reading

See Figure 3.

NOTE This International Standard specifies the tolerance direction of for total cumulative pitch deviation to be along the arc of the tolerance diameter circle in the transverse section. Tolerances are provided in 5.4.2.



F_x = index deviation
f_{pt} = single pitch deviation
F_p = total cumulative pitch deviation
z = tooth number

Figure 3 — Pitch data from single probe device

3.1.10
transmission error
θ_e
deviation of the 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

NOTE See Annex B for discussion of transmission error and single flank composite deviations.

3.2 Fundamental terms and symbols

The terminology and symbols used in this International Standard are listed alphabetically by symbol in Table 1, and alphabetically by term in Table 2. To convey the maximum amount of information, however, the names of a number terms have been rearranged in order to group principle characteristics.

Table 1 — Alphabetical table of symbols, by symbol

Symbol	Term	Where first used (clause/subclause/figure)
$d_{m1, 2}$	Mean pitch diameter (pinion or wheel)	3.1.8
d_T	Tolerance diameter	1
F_{is}	Single-flank composite deviation, total	3.1.6
F_{isT}	Single-flank composite tolerance, total	5.4.6
F_p	Cumulative pitch deviation, total	3.1.9
F_{pT}	Cumulative pitch tolerance, total	5.4.3
F_r	Runout deviation, total	3.1.4
F_{rT}	Runout tolerance	5.4.4
F_x	Index deviation	3.1.1
f_{is}	Single-flank composite deviation, tooth mesh component	3.1.6
$f_{is(design)}$	Single-flank composite deviation, design tooth mesh component	5.4.5
f_{isT}	Single-flank composite tolerance, tooth mesh component	5.4.5
f_{pt}	Single pitch deviation	3.1.7
f_{ptT}	Single pitch tolerance	5.4.2
h_{am}	Addendum, mean	3.1.8
h_{mw}	Working depth, mean	3.1.8
m_{et}	Module, outer transverse	3.1.2
m_{mn}	Module, mean normal	1
R_e	Distance, outer cone	3.1.2
R_i	Distance, inner cone	Figure 1
R_m	Distance, mean cone	3.1.2
$z_{1, 2}$	Number of teeth (pinion or wheel), tooth number	1
β_m	Mean spiral angle	3.1.2
$\delta_{1, 2}$	Pitch angle (pinion or wheel)	3.1.8
θ_e	Transmission error	3.1.10
Characteristic symbols as subscripts		
Symbol	**Term**	
m	Mean	
T	Tolerance	
1	Pinion	
2	Gear	

Table 2 — Alphabetical table of symbols, by term

Symbol	Term	Where first used (clause/subclause/figure)
h_{am}	Addendum, mean	3.1.8
R_m	Cone distance, mean	3.1.2
R_e	Cone distance, outer	1
R_i	Cone distance, inner	Figure 1
F_p	Cumulative pitch deviation, total	3.1.9
F_{pT}	Cumulative pitch tolerance, total	5.4.3
d_T	Diameter, tolerance	3.1.8
F_x	Index deviation	3.1.1
m_{mn}	module, mean normal	3.1.2
m_{et}	module, outer transverse	3.1.2
$z_{1,2}$	Number of teeth (pinion or wheel)	1
$\delta_{1,2}$	Pitch angle (pinion or wheel)	3.1.8
$d_{m1,2}$	pitch diameter, mean (pinion or wheel)	3.1.8
F_r	runout deviation, total	3.1.4
F_{rT}	Runout tolerance	5.4.4
f_{is}(design)	Single-flank composite deviation, design tooth mesh component	5.4.5
f_{is}	Single-flank composite deviation, tooth mesh component	3.1.6
f_{isT}	Single-flank composite tolerance, tooth mesh component	5.4.5
F_{is}	Single-flank composite deviation, total	3.1.6
F_{isT}	Single-flank composite tolerance, total	5.4.6
f_{pt}	Single pitch deviation	3.1.7
f_{ptT}	Single pitch tolerance	5.4.2
θ_e	Transmission error	3.1.10
β_m	Mean spiral angle	3.1.2
h_{mw}	Mean working depth	3.1.8

4 Application of classification system

4.1 General

The classification system is a numeric code identifying the accuracy grade tolerance for a specific gear.

4.2 Accuracy grade classification

4.2.1 General

This International Standard provides for ten accuracy grades, numbered 2 to 11.

Accuracy grade 2 has the smallest tolerances; accuracy grade 11 the largest. These accuracy grades are separated by a uniform geometric progression of tolerances (see 5.2).

4.2.2 Gear accuracy evaluation

Gear accuracy is evaluated by comparing measured deviations with the numerical values calculated according to the equations in 5.4. Measurements should be made relative to a datum axis. See ISO/TR 10064-3 for further information on defining a datum axis.

The accuracy grade is determined for the parameters specified in Table 4; the overall accuracy grade is the largest of these individual accuracy grades. Note that different accuracy grades may be specified for different parameters, if required for specific applications.

In addition, it is recommended that if single-flank composite deviations are not measured, additional contact pattern and tooth thickness checks should be made to verify the gear is fit for purpose. The contact pattern requirements should be agreed upon between customer and supplier prior to manufacture. Refer to ISO/TR 10064-6 for further information on this subject.

4.2.3 Example tolerance tables

For reference only, example tolerance tables are provided in Annex A.

4.3 Tolerance direction

The tolerance direction is specified in Clause 3. It may be normal to the tooth surface, inclined at some angle, or along the arc of a specified circle. If the measurement direction and the tolerance direction differ, the measured value shall be corrected to the tolerance direction.

When the measurement instrument's direction of measurement is normal and the tolerance direction is other than normal, measurement values shall be increased before analysis and comparison to tolerances. Typically, the factor for this adjustment is the cosine of the angle between the normal direction and the specified tolerance direction.

4.4 Additional characteristics

In certain applications, there may be additional characteristics that require tolerances to assure satisfactory performance. For example, if tooth form tolerances, tooth flank tolerances, tooth thickness tolerances, or surface finish tolerances are desirable for special applications, such tolerances are to appear on drawings or purchase specifications. Some methods for measuring these characteristics are discussed in ISO/TR 10064-6.

5 Tolerances

5.1 Tolerance values

Tolerance values for each item that governs accuracy are calculated by equations given in 5.4 and are expressed in micrometers. Values outside the limits of the equations are beyond the scope of this International Standard and are not to be extrapolated. The specific tolerances for such gears shall be agreed upon by the manufacturer and purchaser.

It is assumed that a calibrated measuring instrument of suitable accuracy is used in a proper environment. See ISO/TR 10064-5.

Tolerance direction and measurement diameter are as defined in Clause 3.

5.2 Step factor

The step factor between two consecutive grades is $\sqrt{2}$. Values of the next higher (or lower) grade are determined by multiplying (or dividing) by $\sqrt{2}$. The required value for any accuracy grade may be determined by multiplying the unrounded calculated value for grade 4 by $\sqrt{2}^{(B-4)}$, where B is the number of the required accuracy grade.

5.3 Rounding rules

Values calculated from the equations in 5.4 shall be rounded as follows:

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

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

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

5.4 Tolerance equations

5.4.1 General

All tolerances are defined in the transverse section at the tolerance diameter.

5.4.2 Single pitch tolerance, f_{ptT}

The tolerance for single pitch deviation applies to the absolute value of the plus or minus measurement value. Absolute single pitch tolerance, f_{ptT}, shall be calculated according to Equation (4):

$$f_{ptT} = (0{,}003\, d_T + 0{,}3\, m_{mn} + 5)\left(\sqrt{2}\right)^{(B-4)} \qquad (2)$$

where the range of application is restricted as follows.

Accuracy grades 2 to 11:

$1{,}0 \text{ mm} \leqslant m_{mn} \leqslant 50 \text{ mm}$

$5 \leqslant z \leqslant 400$

$5 \text{ mm} \leqslant d_T \leqslant 2\,500 \text{ mm}$

5.4.3 Total cumulative pitch tolerance, F_{pT}

Total cumulative pitch tolerance, F_{pT}, shall be calculated according to Equation (5):

$$F_{pT} = (0{,}025\, d_T + 0{,}3\, m_{mn} + 19)\left(\sqrt{2}\right)^{(B-4)} \qquad (3)$$

where the range of application is restricted as follows.

Accuracy grades 2 to 11:

$1{,}0 \text{ mm} \leqslant m_{mn} \leqslant 50 \text{ mm}$

$5 \leqslant z \leqslant 400$

$5 \text{ mm} \leqslant d_T \leqslant 2\,500 \text{ mm}$

5.4.4 Runout tolerance, F_{rT}

Runout tolerance, F_{rT}, shall be calculated according to Equation (6).

$$F_{rT} = 0{,}8\left(0{,}025\ d_T + 0{,}3\ m_{mn} + 19\right)\left(\sqrt{2}\right)^{(B-4)} \tag{4}$$

where the range of application is restricted as follows.

Accuracy grades 4 to 11 only:

$1{,}0 \text{ mm} \leqslant m_{mn} \leqslant 50 \text{ mm}$

$5 \leqslant z \leqslant 400$

$5 \text{ mm} \leqslant d_T \leqslant 2\,500 \text{ mm}$

5.4.5 Tooth mesh component single-flank composite tolerance, f_{isT}

5.4.5.1 General

The determination of the single-flank composite tooth mesh component can be accomplished by one of three methods in order of decreasing precision: Method A, B or C.

5.4.5.2 Method A

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

5.4.5.3 Methods B and C

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 $f_{isT\,max}$ and the lowest peak-to-peak amplitude shall not be smaller than $f_{isT\,min}$. 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 bevel 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 using Equations (7) and (8) or, alternatively, Equations (7) and (9):

$$f_{isT\,max} = f_{is(design)} + \left(0{,}375\ m_{mn} + 5{,}0\right)\left(\sqrt{2}\right)^{(B-4)} \tag{5}$$

The value of $f_{isT\,min}$ is the larger of the following:

$$f_{isT\,min} = f_{is(design)} - \left(0{,}375\ m_{mn} + 5{,}0\right)\left(\sqrt{2}\right)^{(B-4)} \text{ or} \tag{6}$$

$$f_{isT\,min} = 0 \tag{7}$$

If the value of $f_{\text{isT min}}$ is negative, use $f_{\text{isT min}} = 0$. The range of application is restricted as follows.

Accuracy grades 2 to 11

$1{,}0 \text{ mm} \leqslant m_{\text{mn}} \leqslant 50 \text{ mm}$

$5 \leqslant z \leqslant 400$

$5 \text{ mm} \leqslant d_{\text{T}} \leqslant 2\,500 \text{ mm}$

If the measuring instrument reads in units of angle, the conversion to micrometers should be done at the tolerance diameter, d_{T}.

The value of $f_{\text{is(design)}}$ can be determined by Method B or C.

Method B: the design tolerance for tooth mesh component single flank composite deviation, $f_{\text{is(design)}}$, for Equations (7) to (9), should be determined with an analysis for the application design and testing conditions. Consideration should be given to selecting the design value so that it includes influences such as mounting variation, variability of flank form and application operating loads. See Annex B for additional information.

Method C: in the absence of a design and test analysis value for the application tooth mesh component single flank composite deviation, $f_{\text{is(design)}}$, it should be determined using Equation (10):

$$f_{\text{is(design)}} = q\, m_{\text{mn}} + 1{,}5 \tag{8}$$

Suggested values for the parameter q are given in Table B.1.

5.4.6 Total single-flank composite tolerance, F_{isT}

The total single-flank composite tolerance, F_{isT}, shall be calculated according to Equation (11):

$$F_{\text{isT}} = F_{\text{pT}} + f_{\text{isT max}} \tag{9}$$

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

Accuracy grades 2 to 11:

$1{,}0 \text{ mm} \leqslant m_{\text{mn}} \leqslant 50 \text{ mm}$

$5 \leqslant z \leqslant 400$

$5 \text{ mm} \leqslant d_{\text{T}} \leqslant 2\,500 \text{ mm}$

6 Application of measuring methods

6.1 Methods of measurement

This International Standard provides classification tolerances and measuring methods for unassembled gears. This clause presents the recommended methods of measurement.

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

Gear geometry may be measured by a number of alternate methods as shown in Table 3. The selection of the particular method depends on the magnitude of the tolerance, size of the gear, production quantities, equipment available, accuracy of gear blanks and measurement costs. Different accuracy grades may be specified for different elements.

The manufacturer or the purchaser could wish to measure one or more of the geometric features of a gear to verify its accuracy grade. However, a gear specified to an accuracy grade shall meet all the individual tolerance requirements applicable to the particular accuracy grade. In addition, if specified, tooth thickness and either contact pattern or tooth form shall be measured in accordance with Tables 3 and 4. Unless otherwise specified, all measurements are taken and evaluated at the tolerance diameter, d_T.

Normally, the tolerances apply to both sides of the teeth unless only one side is specified as the loaded side. In some cases, the loaded side may be specified to a higher accuracy than the non-loaded or minimum-loaded side; if applicable, this information shall be specified on the gear engineering drawing.

When this International Standard is specified, unless otherwise agreed upon, the manufacturer shall select

— the measuring method to be used from among the applicable methods described in this International Standard and summarized in Table 4;

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

— 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 3.

6.2 Recommended measurement control methods

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

The recommended methods of measurement control for each accuracy grade and type of measurement are listed in Tables 3 and 4.

6.3 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 duration, such as a spiral angle deviation. At the other end of the spectrum are short duration irregularities, such as surface roughness. Measurement and control of flank form and short duration roughness is beyond the scope of this International Standard. See ISO/TR 10064-4 and ISO/TR 10064-6.

The tooth mesh component tolerance of the single flank composite deviation requires filtering by definition.

6.4 Tooth contact pattern inspections

Checking tooth contact patterns with a mate or reference gear is a method of inspection for either assembled gears, or gears mounted on a gear testing machine. It provides an indication of the compatibility of the tooth shapes, both up and down the tooth profile, and lengthwise on the tooth. It evaluates that portion of the gear tooth surface which actually makes contact with its mate. With this technique, the areas that contact can be observed by coating the teeth with a very thin layer of marking compound and meshing the gears. A judgement of compatibility may be made by the position and size of the contact area. It does not necessarily indicate compatible tooth shape for loaded conditions. Progressive shifting of the tooth contact pattern around the gear may indicate runout. This International Standard does not relate tooth contact patterns to gear accuracy grades.

Table 3 — Minimum number of measurements

Method designator	Typical measuring method	Minimum number of measurements
Elemental tests		
Single pitch (SP)	Two-probe	All teeth
	Single-probe	All teeth
Total cumulative pitch (AP)	Two-probe	All teeth
	Single-probe	All teeth
Runout (RO)	Ball-probe	All teeth
	Single-probe — index	All teeth
	Two-probe — 180°	All teeth
	Double-flank composite action	All teeth
Tooth form (TF)	CMM or CNC special software [a]	3 teeth approximately equally spaced
Composite tests		
Tooth contact pattern (CP)	Roll test machine	All teeth
Single flank (SF)	Single-flank tester (Annex B)	All teeth
Size		
	Tooth caliper	2 teeth approximately equally spaced
Tooth thickness (TT)	CMM special software	3 teeth approximately equally spaced
	Roll test machine	3 teeth approximately equally spaced

[a] See ISO/TR 10064-6 for further discussion of this method.

Table 4 — Accuracy grades and measuring methods

Tooth size	Module ⩾ 1,0 mm [a]		
Basic requirements [b, c]	TT and (CP or TF) [c]		
Accuracy	Low	Medium	High
Accuracy grade [d]	11 – 9	8 – 5	4 – 2
Minimum requirements [b, e]	RO	SP and RO	SP and AP
Alternative methods [b, e]	(SP and AP) or SF		

[a] For < 1,0 module, see Annex C.

[b] Letter symbols used for measurement identifications are the same as those used in Table 3.

[c] Tooth thickness and either CP or TF shall be measured for all grades.

[d] Noise control requires good conjugacy of tooth form. Good control of TF, CP or SF (tooth mesh component) is necessary. Alternative method SF with (CP and TT) is highly recommended.

[e] Alternative methods may be used in place of minimum acceptable methods.

Annex A
(informative)

Example tolerance tables

A.1 Purpose

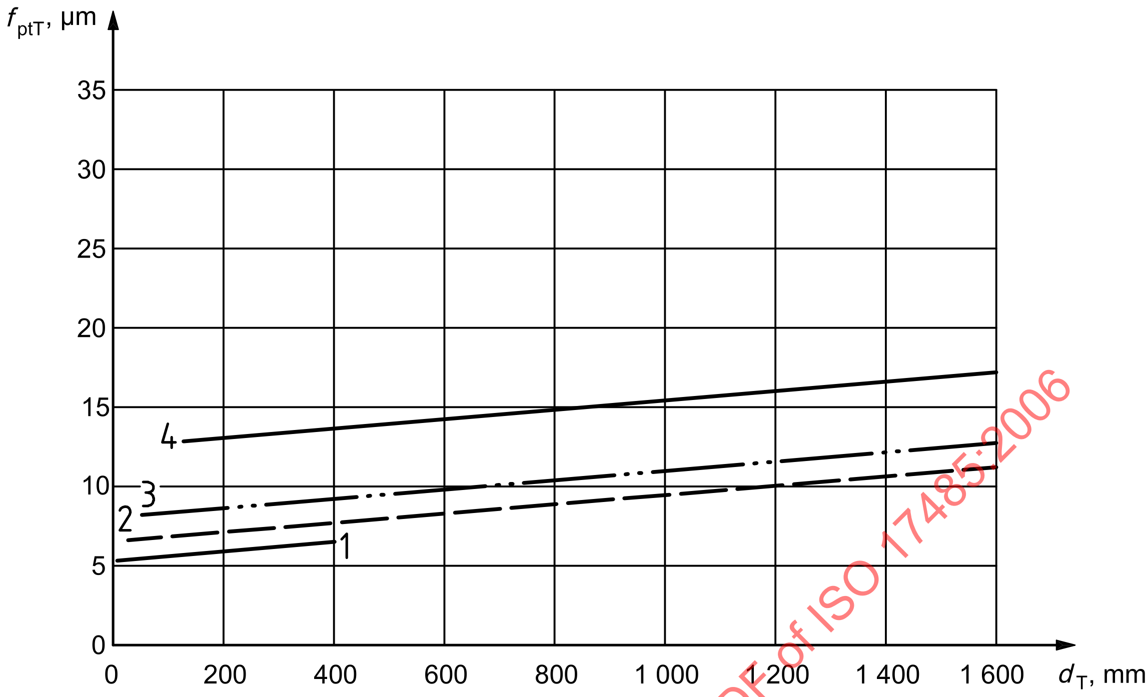
This annex is to provide example values of the tolerances that define the accuracy of bevel gearing. Tables A.1 and A.2 and Figures A.1 and A.2 are determined from the Equations given in 5.4. For the tolerances, application ranges on diameter, number of teeth and module, see 5.4.

Table A.1 — Single pitch tolerance, f_{ptT}, grade 4

Tooth size	Tolerance diameter d_T mm							
Module m_{mn} mm	**100**	**200**	**400**	**600**	**800**	**1 000**	**1 500**	**2 500**
	f_{ptT} µm							
1	5,5	6,0	6,5	—	—	—	—	—
5	7,0	7,0	8,0	8,5	9,0	9,5	11	—
10	8,0	8,5	9,0	10	10	11	13	16
25	—	13	14	14	15	16	17	20
50	—	—	21	22	22	23	25	28

Table A.2 — Total cumulative pitch tolerance, F_{pT}, grade 4

Tooth size	Tolerance diameter d_T mm							
Module m_{mn} mm	**100**	**200**	**400**	**600**	**800**	**1 000**	**1 500**	**2 500**
	F_{pT} µm							
1	22	23	29	—	—	—	—	—
5	23	26	31	36	41	45	58	—
10	25	27	32	37	42	47	60	85
25	—	32	37	42	47	52	64	89
50	—	—	44	49	54	59	72	97



Key

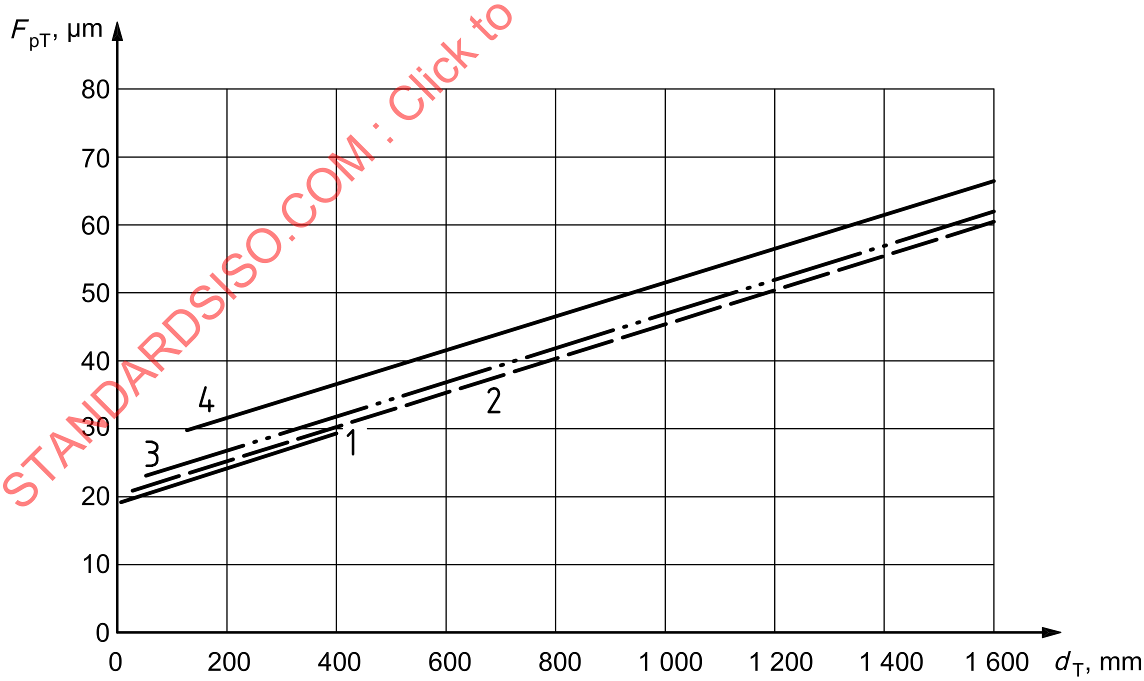
1 1 mm module

2 5 mm module

3 10 mm module

4 25 mm module

Figure A.1 — Single pitch tolerance, f_{ptT}, grade 4



Key

1 1 mm module

2 5 mm module

3 10 mm module

4 25 mm module

Figure A.2 — Total cumulative pitch tolerance, F_{pT}, grade 4

Annex B
(informative)

Single-flank composite measuring method

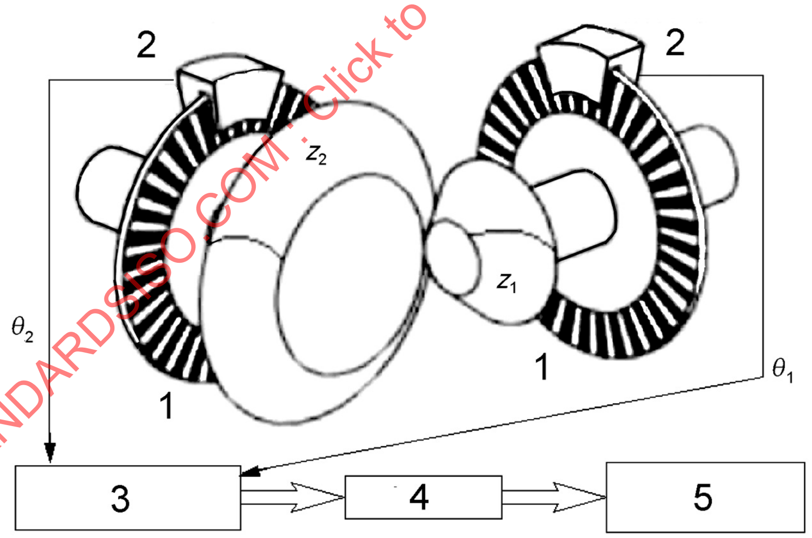
B.1 Purpose

This annex is provided as a discussion of bevel gear transmission error (deviation) and to give a default value for tooth mesh single flank composite deviation, $f_{is(design)}$. With single-flank testing, mating gears roll together at their specific mounting 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 is useful for controlling gear noise and vibration of gear units. It can also be used to detect nicks and burrs.

B.2 Structure of tester and obtained data

Figure B.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 wheel shaft. The transmission error, θ_e, of the gear pair is calculated by Equation (B.1):

$$\theta_e = \theta_2 - \left(\frac{z_1}{z_2}\right)\theta_1 \qquad \text{(B.1)}$$

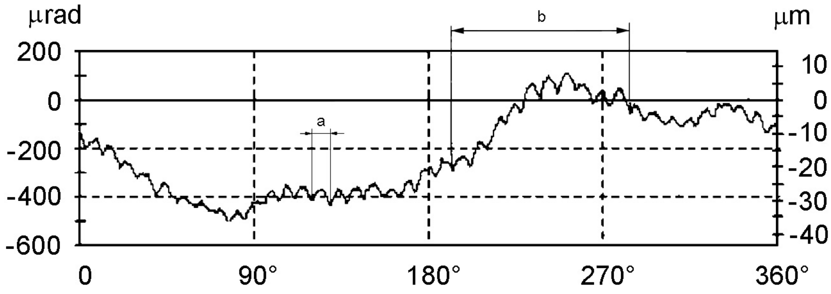


Key

1 rotary encoder
2 reading device
3 calculation of transmission error
4 filtering
5 Fourier transform

Figure B.1 — Schematic view of single-flank tester

The recommended minimum number of measurement points for evaluating a single-flank parameter is 30 points per tooth. Then the data is filtered and Fourier transformed. The example of a transmission wave form shown in Figure B.2 has the complex shape caused by the cumulative deviations of pinion and wheel.



a Tooth pitch.

b One revolution of pinion.

Figure B.2 — Example of transmission error

The small waves within one pitch are caused by tooth form deviations. Figure B.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 B.4 shows the Fourier transformed deviations. Sharp peaks can be seen at the mesh frequency and at the second order mesh frequency. These peak values, called first harmonic and second harmonic, are used to evaluate gear noise level.

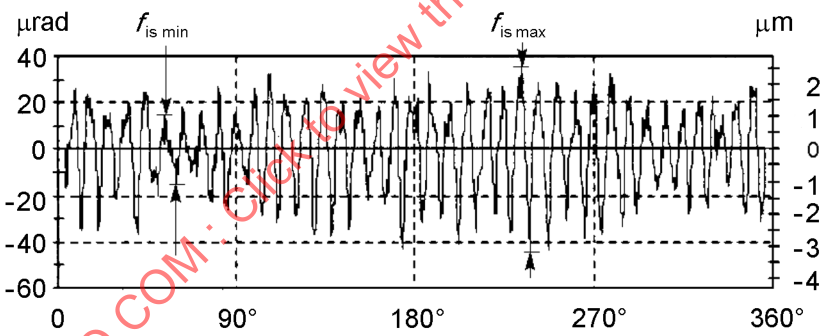
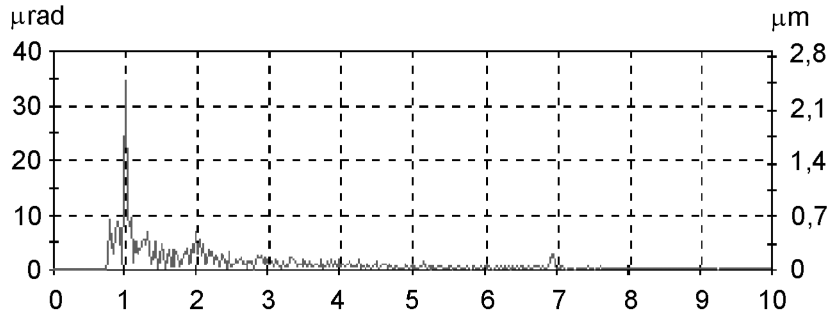
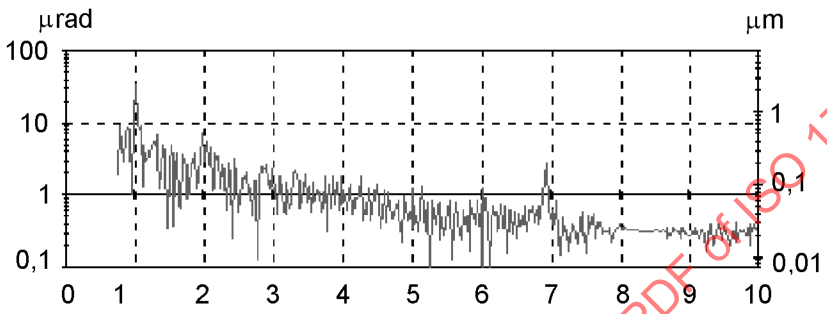


Figure B.3 — High pass filtered, single-flank composite deviations



a) Order of tooth mesh frequency-linear amplitude

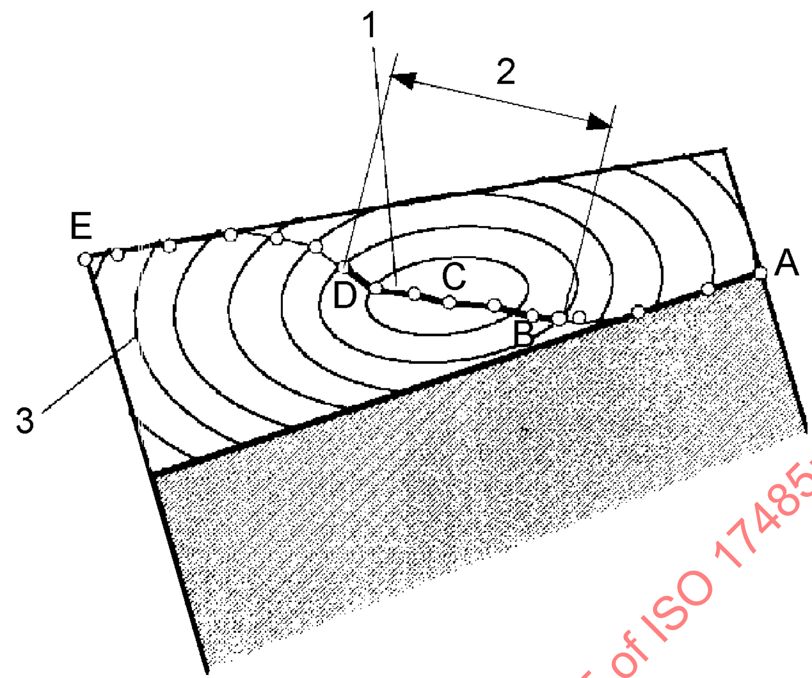


b) Order of tooth mesh frequency-log amplitude

Figure B.4 — Fourier transformed, single-flank composite deviations

B.3 Interpretation of single flank composite deviations

Single-flank composite deviations are composed of tooth form and pitch deviations. In Figure B.5, the elliptical lines show a composite tooth flank form topology that is the relative tooth form modification between pinion and wheel. Generally, bevel gears are designed to have this type of surface topology or ease-off to avoid edge contact under loaded conditions. The line connecting points A to E represents the path of contact between one tooth pair of a spiral bevel gear set. In actual gears however, only the points from B to D are in contact due to transfer of contact from leading to trailing teeth. The line from B to D is therefore the actual path of contact.



Key

1 path of contact

2 path of contact length corresponding to one pitch

3 contour of ease-off

Figure B.5 — Construction of path of contact

Figure B.6 illustrates the effect of ease-off in a typical bevel gear design. The parabolic lines are called motion curves and represent the rotational displacement, θ_e, of the gear relative to the pinion, where p is the angle of one pitch. The points from A to E coincide with the points in Figure B.5. The sections of the motion curves from A to B and from D to E represent the areas where contact is transferred from the leading to trailing teeth. The actual motion curve is the one represented by the thick line.

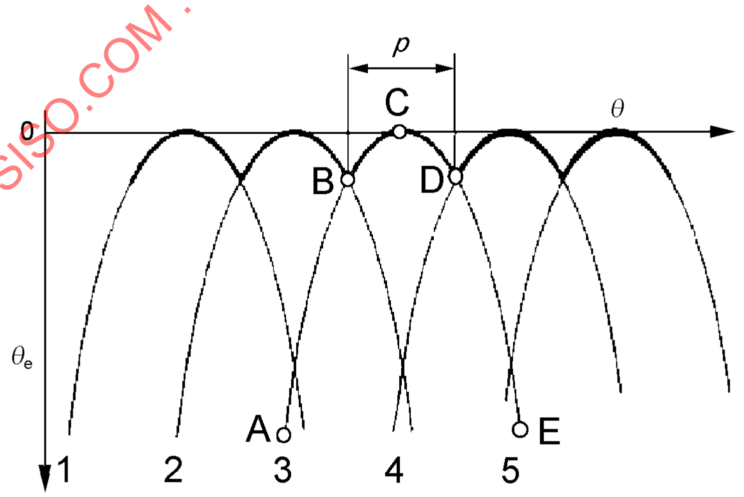


Figure B.6 — Motion curves 1 to 5 of gears with no pitch deviation

Figure B.7 shows two examples of gear motion curves with pitch deviations. Case A shows the effect of a single tooth that is equally thicker on each side than all the rest. The path of contact BD is longer than BD in Figure B.5, because this thicker tooth remains in contact longer. Case B shows a more typical situation where there is a sinusoidal pattern to the cumulative pitch (index) deviations of the gear causing longer then shorter contact regions.

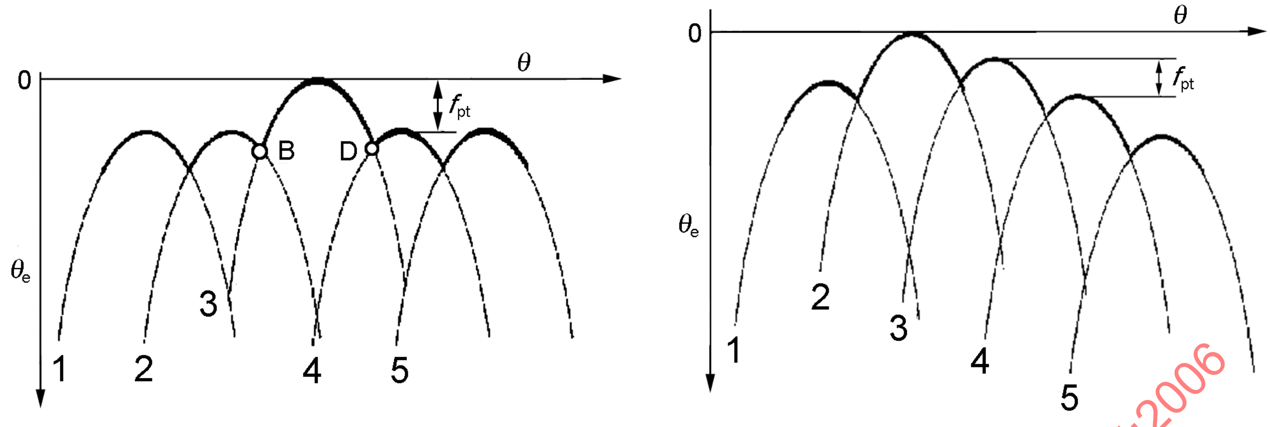


Figure B.7 — Motion curves of gears with pitch deviation

B.4 Single-flank composite design tolerance

With single-flank testing, mating gears roll together at their specified mounting distance with backlash and with only one flank side of the teeth in contact at light or no load. Bevel gears are normally tested as mated pairs. Gears that are lapped in sets should be tested and used as mated pairs. Other types of bevel gears may be tested with a suitable reference mate.

The value for the design tooth mesh component single-flank composite deviation, $f_{is(design)}$, should be determined with an analysis for the application design and the testing conditions (Method B). See Table B.1.

In the absence of a design analysis value for the application, the design tooth mesh component single flank composite deviation, $f_{is(design)}$, should be determined using Equation (10), which contains factor q listed in Table B.1 (Method C).

Single flank testing alone is not a cure for all gear problems. It should be considered as one tool in the overall strategy to assure consistent acceptable performance of bevel gears.

B.5 Typical values

To avoid gear noise problems or prevent premature gear failures typical values for tooth mesh components that are shown in Table B.1 have been used.

It is the responsibility of the designer to specify appropriate tolerances. Further, it should be noted that a visual examination of the shape of the single flank trace is necessary.

Table B.1 — Typical values for amplitudes of single flank composite tooth mesh component deviations

Application	Typical values for amplitudes of single flank composite tooth mesh component deviations µrad	Factor q
Passenger car	< 30	0,05
Truck	20 – 50	1,0
Industrial	40 – 100	2 to 2,5
Aircraft	40 – 200 (80 average)	2,0

Annex C
(informative)

Accuracy of small module bevel gears

C.1 Purpose

This annex provides a system of accuracy relevant to double-flank composite deviations of individual bevel and hypoid gears of less than one module. It specifies the appropriate structure of the gear accuracy system and the tolerance values. It also allows alternative methods, such as CNC instrument or CMM measurements, when small probes are available.

The double-flank composite measurement accuracy system has different grade ranges than those in the main body of this International Standard. In addition, the diameter, numbers of teeth and module ranges are different.

For the purposes of this annex, the terms and definitions given in ISO 1122-1 apply.

C.2 Ranges of parameters

The double-flank composite accuracy system comprises nine accuracy grades for total double-flank composite tolerance, F_{idT}, or tooth-to-tooth double-flank composite tolerance, f_{idT}, of which grade 3 is the highest and grade 11 the lowest. Equations for tolerances and their ranges of validity are provided in C.4. In general, these tolerances cover the following ranges:

$0{,}2 \text{ mm} \leqslant m_{mn} < 1{,}0 \text{ mm}$

$5 \leqslant z \leqslant 300$

$5 \text{ mm} \leqslant d_T \leqslant 300 \text{ mm}$

C.3 Measuring methods

The manufacturer or purchaser may wish to measure one or more of the geometric features of a gear to verify its accuracy grade. However, a gear which is specified to an accuracy grade shall meet all the individual tolerance requirements applicable to the particular accuracy grade and size as noted in Tables C.1 and C.2.

Table C.1 — Measuring methods

Tooth size	Gear accuracy grade [a]	Minimum acceptable method [b, c]	Alternative methods [c, d]
Module < 1,0 mm [e]	All	DF (CP and TT)	SF (CP and TT) or SP, AP (TF and TT) [f]

[a] Noise control requires good conjugacy of tooth form. Good control of TF, CP or SF (tooth-to-tooth) is necessary. Alternative method CP, SF and TT is highly recommended.

[b] Letter symbols used for measurement identifications are the same as those defined in Table C.2.

[c] Alternative methods may be used in place of minimum acceptable methods.

[d] Values for SP, AP or SF are determined by the Equations given in Clause 5.

[e] Limited by availability of small probes.

[f] For module ⩾ 1,0 mm, see Clause 6.

Table C.2 — Minimum number of measurements

Method designator	Typical measuring method	Minimum number of measurements
Elemental tests		
Tooth form (TF) by CMM or CNC gear measuring instruments	CMM or CNC special software [a]	3 teeth approximately equally spaced
Composite tests		
Tooth contact pattern (CP)	Roll test machine	All teeth
Double flank (DF)	Double-flank tester	All teeth
Single flank (SF)	Single-flank tester (Annex B)	All teeth
Size		
Tooth thickness (TT)	Tooth gauge	2 teeth approximately equally spaced
	CMM special software	3 teeth approximately equally spaced
	Roll test machine	3 teeth approximately equally spaced

[a] See ISO/TR 10064-6 for further discussion of this method.

C.4 Tolerances

C.4.1 General

Tolerance values for each item that governs accuracy are calculated by the Equations given in C.4.2 and C.4.3.

Values outside the limits of the equations are beyond the scope of this International Standard and shall not be extrapolated. The specific tolerances for such gears shall be agreed upon by the buyer and the seller.

C.4.2 Tooth-to-tooth double-flank composite tolerance, f_{idT}

The tooth-to-tooth double-flank composite tolerance, f_{idT}, shall be calculated according to Equation C.1:

$$f_{idT} = 0{,}2\left(0{,}025\, d_T + 0{,}3\, m_{mn} + 19\right)\left(\sqrt{2}\right)^{(B-4)} \quad \text{(C.1)}$$

where the range of application is restricted as follows.

Accuracy grades 3 to 11:

$0{,}2 \text{ mm} \leqslant m_{mn} < 1{,}0 \text{ mm}$

$5 \leqslant z \leqslant 300$

$5 \text{ mm} \leqslant d_T \leqslant 300 \text{ mm}$

The value of tooth-to-tooth double flank composite tolerance, f_{idT}, shall be rounded in accordance with 5.3.

Tooth-to-tooth composite tolerances are based on the mounting distance change within the smallest envelope that includes all the (360°/z) changes in amplitude. This envelope is determined by establishing a mean waveform of the trace and moving it in the plus and minus amplitude directions to enclose all peaks. The mean waveform can be established manually or by signal processing using a polynomial fit (filtering). See Annex D.

C.4.3 Total double-flank composite tolerance, F_{idT}

The total double-flank composite tolerance, F_{idT}, shall be calculated using Equation (C.2).

$$F_{idT} = 1{,}08\left(0{,}025\, d_T + 0{,}3\, m_{mn} + 19\right)\left(\sqrt{2}\right)^{(B-4)} \quad \text{(C.2)}$$

where the range of application is restricted as follows.

Accuracy grades 3 to 11:

$0{,}2\ \text{mm} \leqslant m_{mn} < 1{,}0\ \text{mm}$

$5 \leqslant z \leqslant 300$

$5\ \text{mm} \leqslant d_T \leqslant 300\ \text{mm}$

The value of total double flank composite tolerance, F_{idT}, shall be rounded in accordance with 5.3.

Annex D
(informative)

Interpretation of composite data

D.1 Purpose

This annex provides a comparison between the traditional and a new proposed method of evaluation of composite data. The new method can be applied to single-flank as well as double-flank composite tests. The purpose of the new method is to provide information that is more useful for diagnostic purposes and quality improvements.

D.2 Introduction

D.2.1 General

See Annex C for more information on the double-flank composite testing method.

See Annex B for more information on the single-flank composite testing method.

D.2.2 Chart information

Double-flank composite data charts are made up primarily of information related to runout and deviations in tooth form.

Single-flank composite data charts are made up primarily of information related to tangential index deviation (total cumulative pitch deviation) and deviations in tooth form.

D.2.3 Traditional interpretation

Double-flank composite measurements were toleranced for total composite deviation, $F_{\text{i (old)}}$, and tooth-to-tooth composite deviation, $f_{\text{i (old)}}$. They were interpreted from the charts as shown in Figure D.1. The total composite deviation was read as the difference between the highest-to-lowest point on the chart. The tooth-to-tooth deviation was read as the greatest change in any 360°/z part of the chart.

This was acceptable for evaluation of the final gear quality relative to the application for some purposes. However, it doesn't tell the true picture as far as diagnostic purposes. For example, it does not help in the case of determining noise potential. Also, in attempts to evaluate the manufacturing process, it gave a distorted picture of the tooth form that the machine and tool is producing.

A problem with this analysis is that the greatest tooth-to-tooth deviation will be along the part of the runout curve having the greatest slope. This has the effect of distorting the amplitude of the data relating to that particular tooth.

For the same quality of tooth form and runout, the tooth-to-tooth deviation would be greater for a gear with a lower number of teeth than it would for those with higher numbers of teeth. See Figure D.2 a) and b) for a comparison.

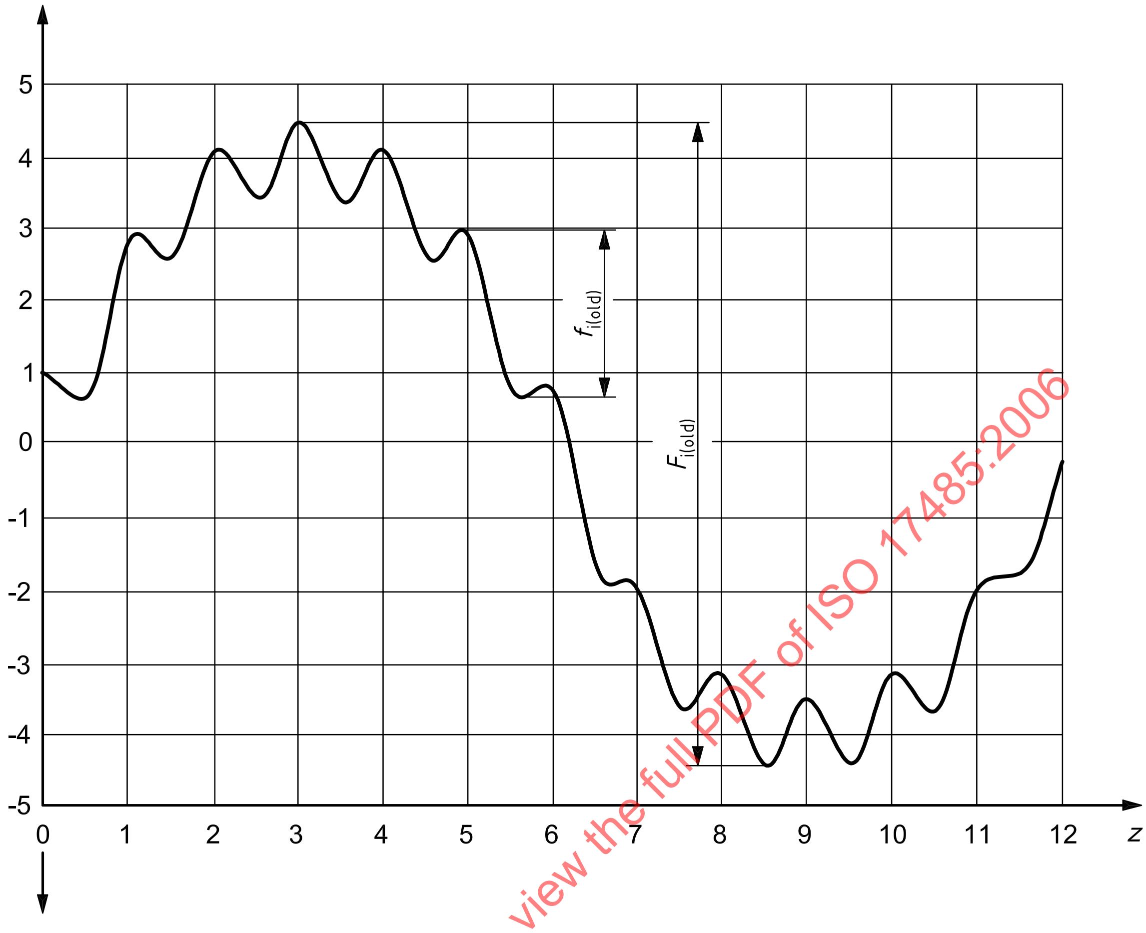
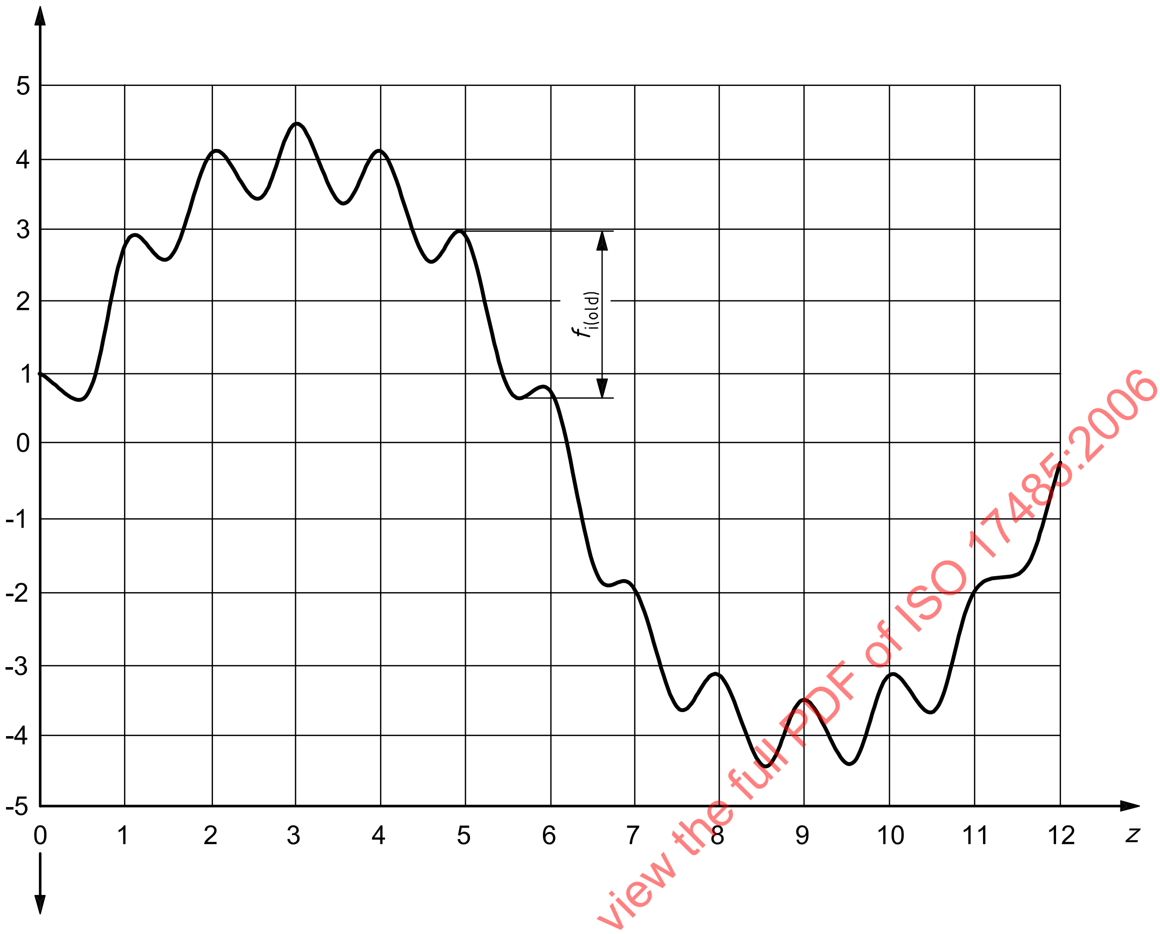


Figure D.1 — Strip chart of double flank composite test



a) **Low number of teeth** (composite tooth-to-tooth 12 tooth gear)

Figure D.2 — Double-flank composite test