TECHNICAL REPORT

ISO TR 10064-2

First edition
1996-03-01

Cylindrical gears — Code of inspection practice —

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

Engrenages cylindriques — Code pratique de réception —
Partie 2: Contrôle relatif aux écarts composés radiaux, au faux-rond, à l'épaisseur de dent et au jeu entre dents

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FOREWORD

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

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

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

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

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

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 Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 10064-2, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 60, *Gears*.

Together with definitions and values allowed for gear element deviations, the International Standard ISO 1328:1975 also provided advice on appropriate inspection methods.

In the course of revising ISO 1328:1975, it was agreed that the description and advice on gear inspection methods should be brought up to date. Because of necessary enlargement and other considerations, the Technical Committee decided that the relevant sections should be published under separate cover as a Technical Report, type 3. It was decided that, together with this Technical Report, a system of documents as listed in clause 2 (References) and annex B (Bibliography) should be established for definitive information.

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

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

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

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

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

Cylindrical gears — Code of inspection practice —

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

1 Scope

This part of the Technical Report constitutes a code of practice dealing with inspection relevant to radial composite deviations, runout, tooth thickness and backlash of cylindrical involute gears; i.e., with measurements referred to double flank contact.

In providing advice on gear checking methods and the analysis of measurement results, it supplements the standard ISO 1328-2. Most of the terms used are defined in ISO 1328-2.

Annex A provides a method to select gear tooth thickness tolerances and minimum backlash of a gear mesh. Suggested values for minimum backlash are included.

2 References

ISO 53: 1974	Cylindrical gears for general and heavy engineering - Basic rack;
ISO 54: 1977	Cylindrical gears - Modules and diametral pitches of cylindrical gears for general and heavy engineering;
ISO 1328-1:1995	Cylindrical gears - Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth;
ISO 1328-2:	Cylindrical gears - Definitions and allowable values of deviations relevant to radial composite deviations and runout information *(in the state of preparation)*;
ISO/TR 10064-1: 1992	Cylindrical gears - Code of inspection practice - Inspection of corresponding flanks of gear teeth;
ISO/TR 10064-3:	Cylindrical gears - Recommendations relative to blanks, shaft center distance and parallelism of axes *(in the state of preparation)*.

3 Symbols, corresponding terms and definitions

3.1 Lower case symbols

a	center distance	mm
b	facewidth	mm
d	reference diameter	mm
d_b	base diameter	mm
d_a	tip diameter	mm
f_e	eccentricity	mm
f_i''	tooth-to-tooth radial composite deviation	µm
h_a	addendum	mm
h_c	reference chordal height	mm
m_n	normal module	-
s_n	normal tooth thickness	mm
s_{nc}	normal chordal tooth thickness	mm
x	profile shift coefficient	-
z	number of teeth	-

3.2 Upper case symbols

D_M	diameter of ball or cylinder used for measurement	mm
E_{sni}	lower tooth thickness allowance	mm
E_{sns}	upper tooth thickness allowance	mm
F_i''	total radial composite deviation	µm
F_r	runout	µm
F_r''	runout by composite test	µm
M_d	dimension over balls or cylinders (pins)	mm
W_k	base tangent length	mm

3.3 Greek symbols

α_{Mt}	pressure angle in transverse plane	°
α_n	normal pressure angle	°
β	helix angle	°
δ	prism (anvil) half angle	°
ε_β	overlap ratio	-
η	tooth space half angle	°
ψ	tooth thickness half angle	°

3.4 Subscript symbols

0	tool	b	base
1	pinion	t	transverse
2	wheel (gear)	w	working
3	master gear	y	any (specified) diameter

3.5 Definitions

3.5.1 Definitions with regard to composite deviation

The **reference axis** of a component is defined by means of datum surfaces. In most cases the axis of the bore can be adequately represented by the axis of the mating work arbor (see ISO/TR 10064-3).

The **geometric axis of the teeth** for radial composite deviation is that axis which, if used for the measurement, would give the minimum root mean square (rms) total composite deviation over a complete revolution.

3.5.2 Definitions with regard to tooth thickness

Nominal tooth thickness, s_n, on the reference cylinder in a normal plane is equal to the theoretical value for meshing without backlash with a mating gear, which also has the theoretical tooth thickness, on the basic center distance. The nominal tooth thickness is calculated using the following equations:
for external gears,

$$s_n = m_n \left(\frac{\pi}{2} + 2 \tan \alpha_n x \right) \qquad \text{...(1)}$$

for internal gears,

$$s_n = m_n \left(\frac{\pi}{2} - 2 \tan \alpha_n x \right) \qquad \text{...(2)}$$

For helical gears, the value of s_n is measured in the normal plane.

Maximum and minimum limits of tooth thickness, s_{ns} and s_{ni}, are the two extreme permissible sizes of tooth thickness between which the actual size should lie, the limits of size being included. See figure 1.

The upper and lower (E_{sns} and E_{sni}) **tooth thickness allowances** define the limits of gear tooth thickness. See equations 3 and 4 and figure 1.

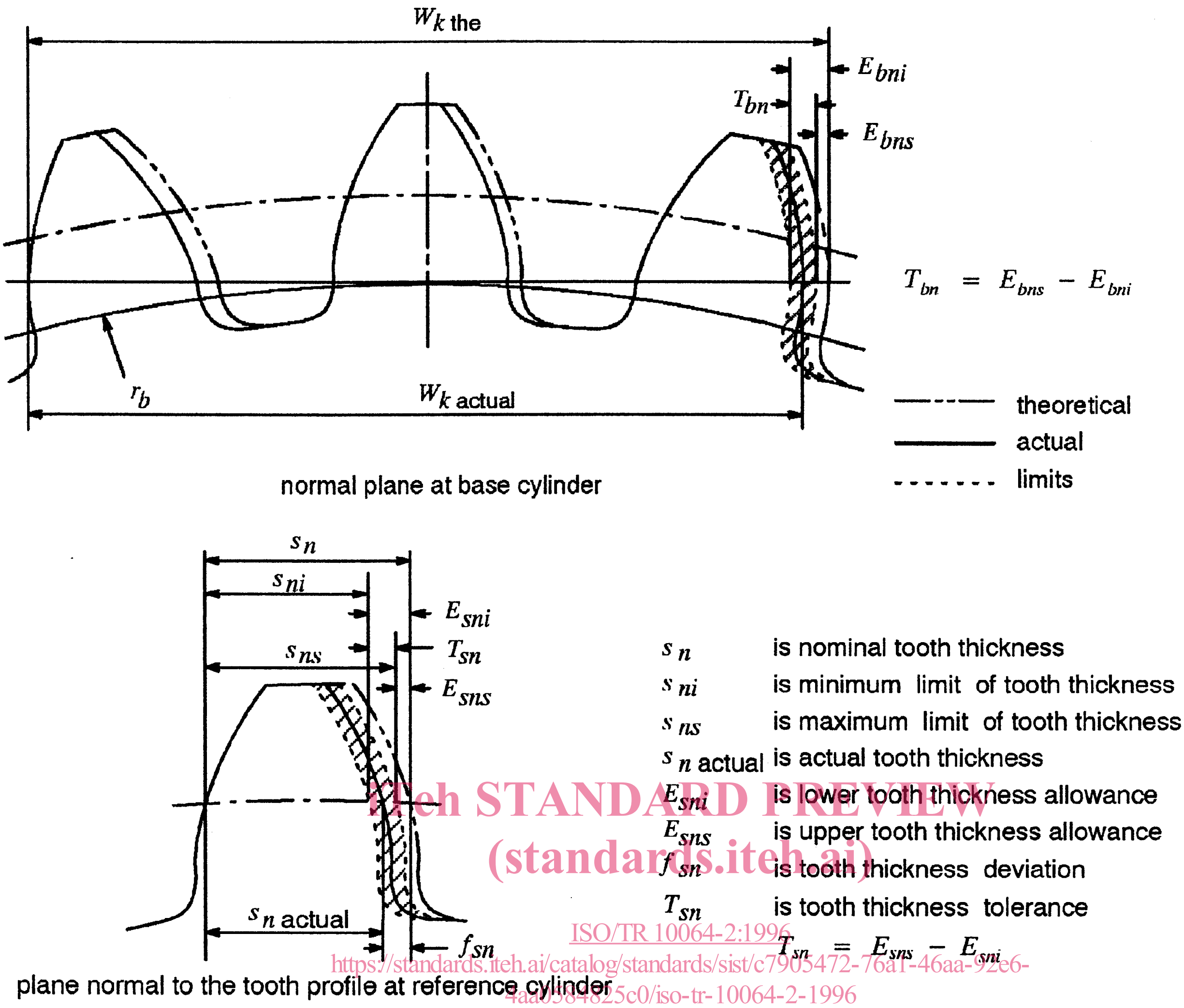


Figure 1 - Span and tooth thickness allowances

$$E_{sns} = s_{ns} - s_n \quad \text{...(3)}$$

$$E_{sni} = s_{ni} - s_n \quad \text{...(4)}$$

Tooth thickness tolerance, T_{sn}, is the difference between the upper and the lower tooth thickness allowance.

$$T_{sn} = E_{sns} - E_{sni} \quad \text{...(5)}$$

The design values of tooth thickness are usually established from engineering considerations of gear geometry, gear tooth strength, mounting and considerations of backlash. The methods for establishing design tooth thicknesses for given applications are beyond the scope of this document.

Actual tooth thickness, $s_{n\ \mathrm{actual}}$, is the tooth thickness determined by measurement.

Functional tooth thickness, s_{func}, is the maximum tooth thickness value obtained on a radial composite action test (double flank) by means of a calibrated master gear.

It is a measurement which encompasses the effects of element deviations in profile, helix, pitch, etc., similar to the concept of maximum material condition, see 6.5. It should never exceed the design tooth thickness.

The **Effective tooth thickness** of a gear will be different than the measured tooth thickness by an amount equal to all the combined effects of the tooth element deviations and mounting, similar to functional tooth thickness.

It is the final envelope condition which encompasses all the effects which must be considered to determine the maximum material condition.

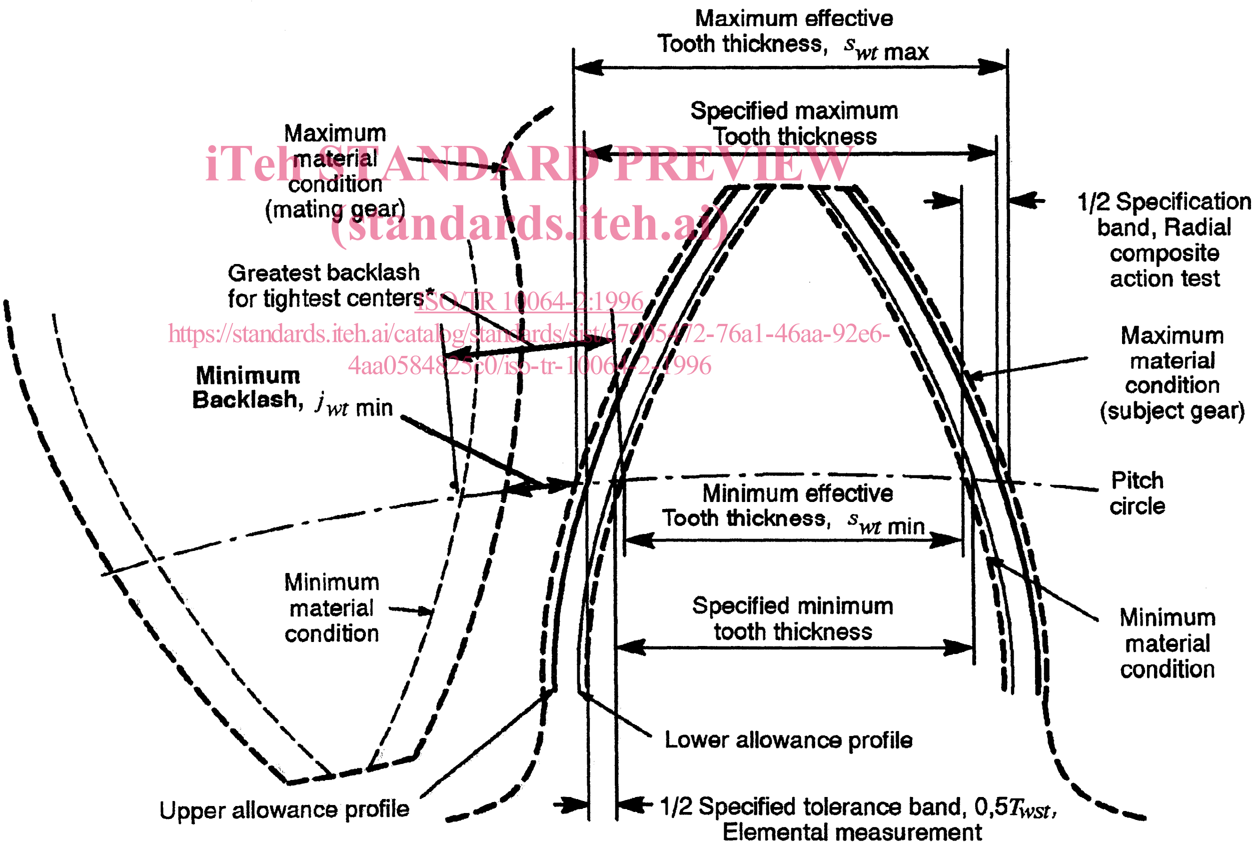
The tooth element deviations of mating gears may have an additive effect or may cancel each other at various angular positions within a given mesh. It is not possible to segregate the individual tooth element deviations from the effective tooth thickness.

3.5.3 Definitions with regard to backlash

Backlash is the clearance between the non-working flanks of two mating gears when their working flanks are in contact, as shown in figure 2.

Note: Figure 2 is drawn at the position of tightest center distance; if center distance is increased backlash will increase. The maximum effective tooth thickness (minimum backlash) will be different than the measured tooth thickness by an amount equal to all the combined effects of the tooth element deviations, and mounting, similar to functional tooth thickness. It is the final envelope condition which encompasses all the effects which must be considered to determine the maximum material condition.

Usually the backlash under stabilized working conditions (working backlash) is different from (smaller than) the backlash which is measured when the gears are mounted in the housing under static conditions (assembly backlash).



* THIS FIGURE IS DRAWN AT THE POSITION OF TIGHTEST CENTER DISTANCE;
if center distance is increased backlash will increase.

Figure 2 - Tooth thickness, transverse plane

Circumferential backlash, j_{wt}, (figure 3) is the maximum length of arc of the pitch circle through which a gear can be rotated when the mating gear is fixed.

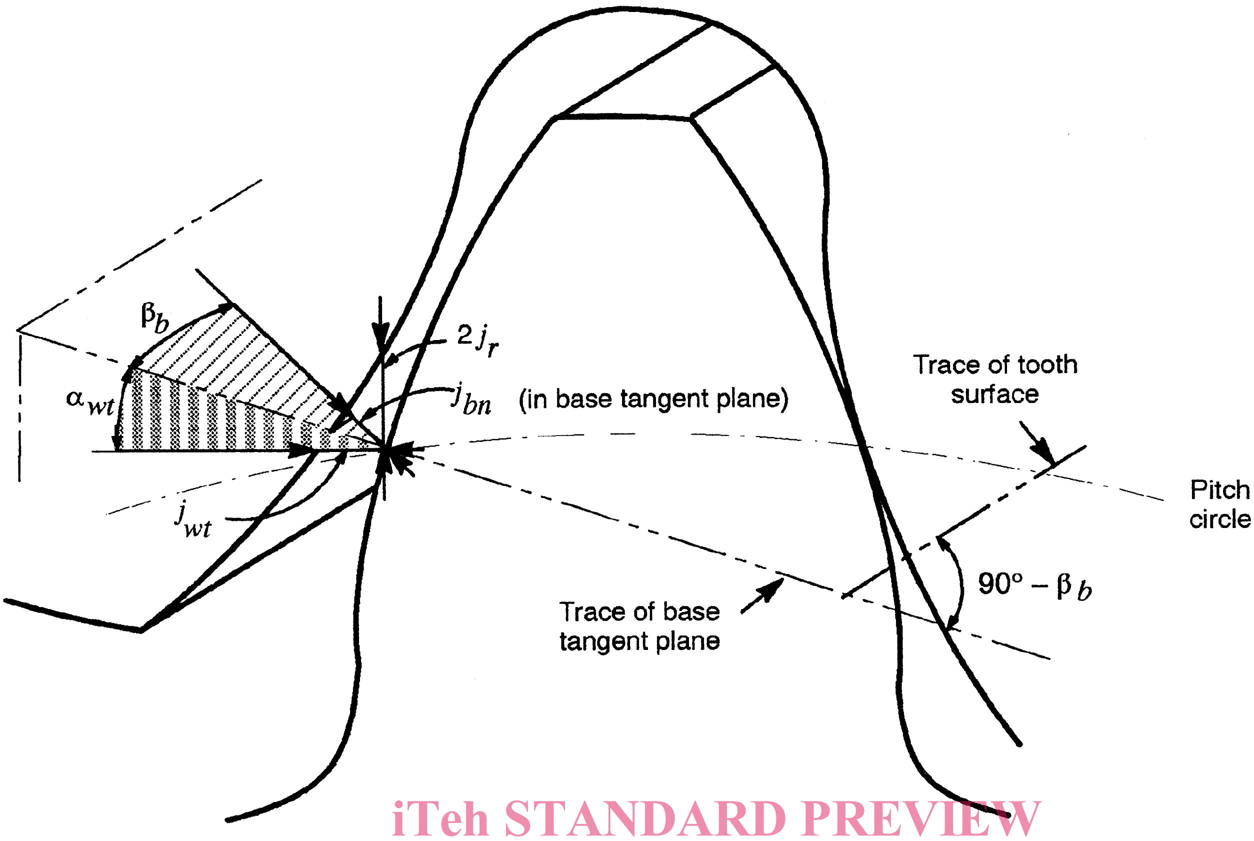


Figure 3 - Relationship between circumferential j_{wt}, normal j_{bn}, and radial j_r backlash

Normal backlash, j_{bn}, (figure 3) is the shortest distance between non-working flanks of two gears when the working flanks are in contact. The relationship with the circumferential backlash, j_{wt}, is in accordance with the following equation:

$$j_{bn} = j_{wt} \cos \alpha_{wt} \cos \beta_b \quad ...(6)$$

Radial backlash, j_r, (figure 3) is the amount by which the center distance has to be diminished till the position in which left and right flanks of mating gears are in contact.

$$j_r = \frac{j_{wt}}{2 \tan \alpha_{wt}} \quad ...(7)$$

Minimum backlash, $j_{wt\ min}$, is the minimum circumferential backlash on the pitch circle when the gear tooth with the greatest allowable effective tooth thickness is in mesh with the mating gear tooth having its greatest allowable effective tooth thickness, at the tightest allowable center distance, under static conditions (figure 2).

The tightest center distance is the minimum working center distance for external gears and the maximum working center distance for internal gears.

Maximum backlash, $j_{wt\ max}$, is the maximum circumferential backlash on the pitch circle when the gear tooth with the smallest allowable effective tooth thickness is in mesh with the mating gear tooth having its smallest allowable effective tooth thickness at the largest allowable center distance under static conditions (figure 2).

4 Measurement of radial composite deviations

4.1 Checking principle

Radial composite deviations are checked on a device on which pairs of gears are assembled with one gear on a fixed spindle, the other on a spindle carried on a slide provided with a spring arrangement enabling the gears to be held radially in close mesh (see figure 4). During rotation, variation of center distance is measured and when desired, a diagram is generated.

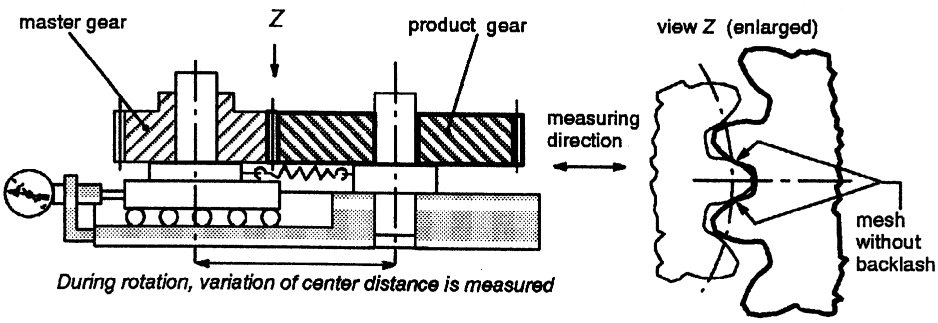


Figure 4 - Principle of measuring radial composite deviations

For most inspection purposes, product gears are tested against a master gear. Master gears are usually required to be so accurate that their influence on radial composite deviations can be neglected in which case an acceptable record is generated during one revolution of the product gear.

The total radial composite deviation F_i'' of the gear under inspection is equal to the maximum variation of center distance during one revolution. It can be determined from the recorded diagram. The tooth-to-tooth radial composite deviation f_i'' is equal to the variation of center distance during rotation through one pitch angle (see figure 5).

The tolerance values given in ISO 1328-2 are valid for measurements made using a master gear.

It is important to note that the accuracy and design of the master gear, especially its pressure angle of engagement with the product gear, can influence the test results. The master gear should have sufficient depth of engagement to be capable of contact with the entire active profile of the product gear but should not contact its non-active or root parts. Such contact can be avoided when the master gear teeth are thick enough to compensate for the product gear backlash allowance.

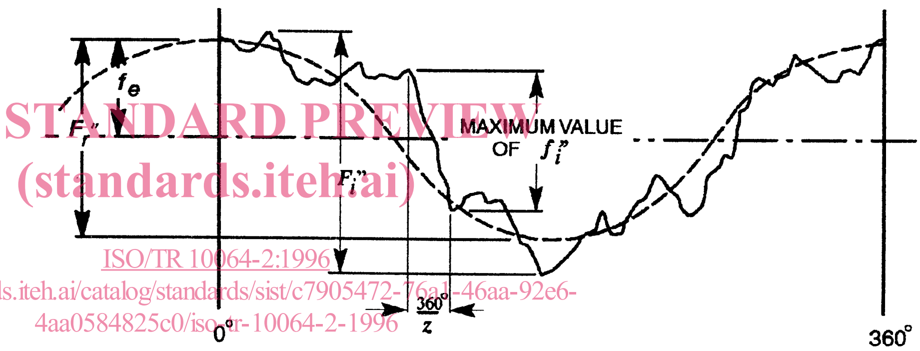


Figure 5 - Radial composite deviation diagram

When they are to be used for the quality grading of accurate gears, the accuracy of the master gear and the measuring procedure used should be agreed between the purchaser and manufacturer.

The tolerances have been established for spur gears and can be used to determine an accuracy grade. When used for helical gears, the master gear facewidth should be such that $\varepsilon_{\beta\ test}$ is less than or equal to 0,5 with the product gear. The design of the master gear shall be agreed upon between purchaser and manufacturer. The overlap ratio, $\varepsilon_{\beta\ test}$, may influence the results of radial composite measurements of helical gears. The effects of profile deviations, which would be evident with spur gears, may be concealed because of the multiple tooth and diagonal contact lines with helical gears.

A chart recording of approximate sinusoidal form (with amplitude f_e) over a single revolution indicates eccentricity, f_e , of the gear teeth. Reference to figure 5 shows how such a sinusoidal curve can be drawn on the diagram. Eccentricity of a gear is the deviation between the geometrical axis of the teeth and the reference axis (i.e., the bore or shaft).

4.2 The utility of radial composite deviation data

Radial composite deviations include components from the combined deviations of right and left flanks. Therefore, determination of the individual deviations of corresponding flanks is not feasible. The measurement of radial composite deviations quickly provides information on deficiencies of quality related to the production machine, the tool or the product gear setup. The method is chiefly used for carrying out checking of large quantities of production gears, as well as fine pitch gears.

Tooth-to-tooth composite deviations occurring at each pitch increment tend to indicate profile deviations (often profile slope deviations). A large isolated tooth-to-tooth composite deviation may indicate a large single pitch deviation or damaged tooth (see figure 6).

With appropriate calibration of the product gear setup and checking methods, the measuring process can also be used to determine the center distance at which the product gear may be meshed with minimum backlash. See ISO/TR 10064-3 for recommendations on shaft center distance and parallelism of axes. Furthermore, the procedure is useful for checking gears required to operate with minimum backlash, since the range of functional tooth thickness can readily be derived from the radial composite deviations.

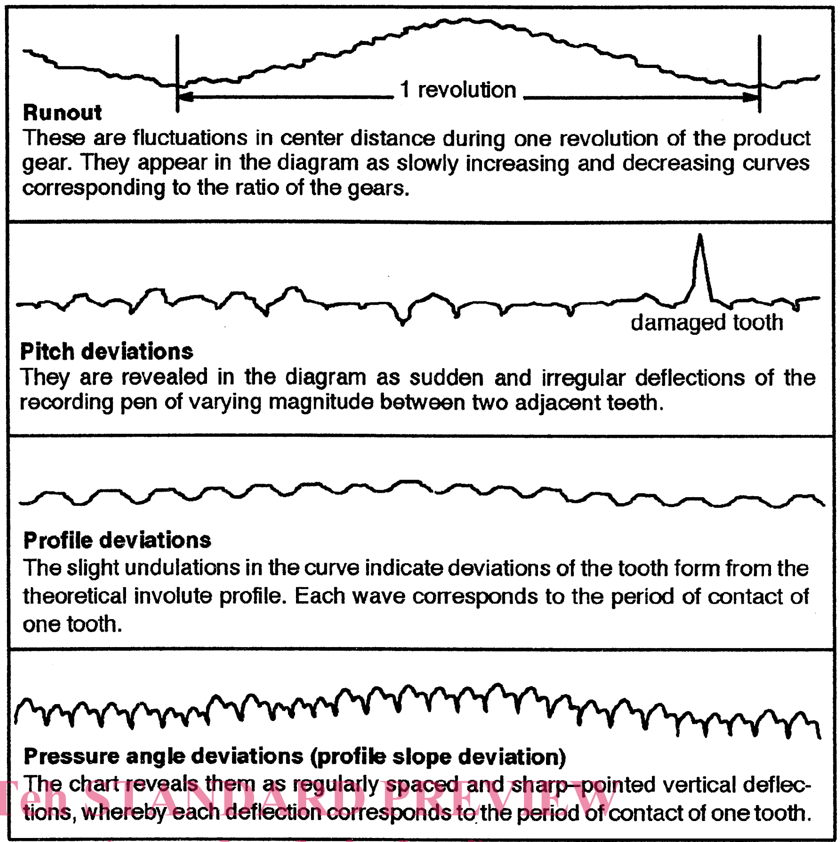


Figure 6 - Interpretation of radial composite deviation

For the determination of an accuracy grade:

a) For a spur gear, the product gear is to be checked against a master gear capable of making 100% contact with the active flanks. See ISO 1328-2 clause 5.5. The tolerance values of total and tooth-to-tooth radial composite deviations to determine an accuracy grade for spur gears are given in ISO 1328-2. It is emphasized that because of the simultaneous contributions from both sets of tooth flanks, such an accuracy grade cannot be directly related to an accuracy grade determined by inspection of individual element deviations.

b) For a helical gear, although the tolerances in ISO 1328-2 are for spur gears, when agreed between purchaser and manufacturer they also can be used for evaluation, provided that $\varepsilon_{\beta\ test}$ with the master gear is appropriate, as described in 4.1.

5 Measurement of runout, determining eccentricity

5.1 Measuring principle

Relative to the gear reference axis, the runout, F_r, of gear teeth is the difference between the maximum and the minimum radial positions of a suitable probe tip: ball, anvil, cylinder or prism, which is placed successively in each tooth space as the gear is rotated (see figure 7).

If a ball, cylinder, or anvil that contacts both sides of a tooth space is used, the tolerance tables in ISO 1328-2 Annex B may be applied. In some instances, it is desirable to use a rider that contacts both sides of a tooth. If this is done, the tolerance tables are not intended to apply.

The diameter of the ball shall be selected such that it contacts the tooth at mid-tooth depth and it should be placed at mid-facewidth (see 6.3 for the calculation of ball diameter).