INTERNATIONAL STANDARD

ISO 6336-3

Third edition
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Corrected version
2020-11

Calculation of load capacity of spur and helical gears —

Part 3:
Calculation of tooth bending strength

Calcul de la capacité de charge des engrenages cylindriques à dentures droite et hélicoïdale —

Partie 3: Calcul de la tenue en fatigue à la flexion en pied de dent

Reference number
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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

This third edition cancels and replaces the second edition (ISO 6336-3:2006), which has been technically revised. It also incorporates the Technical Corrigendum ISO 6336-3:2006/Cor.1:2008.

The main changes compared to the previous edition are as follows:

— modification of the Y_β factor in Clause 8 "Helix angle factor, Y_β";

— modification of the Y_F factor in 6.2 “Calculation of the form factor, Y_F: Method B”;

— integration of 6.2.4 "Tooth root normal chord, s_{Fn}, radius of root fillet, ρ_F, bending moment arm, h_{Fe}, for external gears generated with a shaper cutter";

— integration of 6.2.5 "Tooth root normal chord, s_{Fn}, radius of root fillet, ρ_F, bending moment arm, h_{Fe}, for internal gears generated with a shaper cutter";

— integration of a new Annex C.

A list of all parts in the ISO 6336 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This corrected version of ISO 6336-3:2019 incorporates the following corrections:

— the indication of the 90° angle in the middle of Figure 5 b) has been corrected.

Introduction

ISO 6336 (all parts) consists of International Standards, Technical Specifications (TS) and Technical Reports (TR) under the general title *Calculation of load capacity of spur and helical gears* (see Table 1).

— International Standards contain calculation methods that are based on widely accepted practices and have been validated.

— Technical Specifications (TS) contain calculation methods that are still subject to further development.

— Technical Reports (TR) contain data that is informative, such as example calculations.

The procedures specified in parts 1 to 19 of the ISO 6336 series cover fatigue analyses for gear rating. The procedures described in parts 20 to 29 of the ISO 6336 series are predominantly related to the tribological behavior of the lubricated flank surface contact. Parts 30 to 39 of the ISO 6336 series include example calculations. The ISO 6336 series allows the addition of new parts under appropriate numbers to reflect knowledge gained in the future.

Requesting standardized calculations according to the ISO 6336 series without referring to specific parts requires the use of only those parts that are currently designated as International Standards (see Table 1 for listing). When requesting further calculations, the relevant part or parts of the ISO 6336 series need to be specified. Use of a Technical Specification as acceptance criteria for a specific design need to be agreed in advance between the manufacturer and the purchaser.

Table 1 — Parts of the ISO 6336 series (status as of DATE OF PUBLICATION)

Calculation of load capacity of spur and helical gears	International Standard	Technical Specification	Technical Report
Part 1: Basic principles, introduction and general influence factors	X		
Part 2: Calculation of surface durability (pitting)	X		
Part 3: Calculation of tooth bending strength	X		
Part 4: Calculation of tooth flank fracture load capacity		X	
Part 5: Strength and quality of materials	X		
Part 6: Calculation of service life under variable load	X		
Part 20: Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) — Flash temperature method *(replaces: ISO/TR 13989-1)*		X	
Part 21: Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) — Integral temperature method *(replaces: ISO/TR 13989-2)*		X	
Part 22: Calculation of micropitting load capacity *(replaces: ISO/TR 15144-1)*		X	
Part 30: Calculation examples for the application of ISO 6336 parts 1, 2, 3, 5			X
Part 31: Calculation examples of micropitting load capacity *(replaces: ISO/TR 15144-2)*			X

The maximum tensile stress at the tooth root, which may not exceed the permissible bending stress for the material, is the basis for rating the bending strength of gear teeth. The stress occurs in the “tension fillets” of the working tooth flanks. If load-induced cracks are formed, the first of these often appears in the fillets where the compressive stress is generated, i.e. in the “compression fillets”, which are those of the non-working flanks. When the tooth loading is unidirectional and the teeth are of conventional shape, these cracks seldom propagate to failure. Crack propagation ending in failure is most likely to stem from cracks initiated in tension fillets.

The endurable tooth loading of teeth subjected to a reversal of loading during each revolution, such as “idler gears”, is less than the endurable unidirectional loading. The full range of stress in such circumstances is more than twice the tensile stress occurring in the root fillets of the loaded flanks. This is taken into consideration when determining permissible stresses (see ISO 6336-5).

When gear rims are thin and tooth spaces adjacent to the root surface narrow (conditions which can particularly apply to some internal gears), initial cracks commonly occur in the compression fillet. Since, in such circumstances, gear rims themselves can suffer fatigue breakage, special studies are necessary. See Clause 1.

Several methods for calculating the critical tooth root stress and evaluating some of the relevant factors have been approved. See ISO 6336-1.

Calculation of load capacity of spur and helical gears —

Part 3: Calculation of tooth bending strength

IMPORTANT — The user of this document is cautioned that when the method specified is used for large helix angles (β > 30°) and large normal pressure angles (α_n > 25°), the calculated results should be confirmed by experience as by Method A.

1 Scope

This document specifies the fundamental formulae for use in tooth bending stress calculations for involute external or internal spur and helical gears with a rim thickness $s_R > 0{,}5\ h_t$ for external gears and $s_R > 1{,}75\ m_n$ for internal gears. In service, internal gears can experience failure modes other than tooth bending fatigue, i.e. fractures starting at the root diameter and progressing radially outward. This document does not provide adequate safety against failure modes other than tooth bending fatigue. All load influences on the tooth root stress are included in so far as they are the result of loads transmitted by the gears and in so far as they can be evaluated quantitatively.

This document includes procedures based on testing and theoretical studies such as those of Hirt[11], Strasser[14] and Brossmann[10]. The results are in good agreement with other methods (References [5], [6], [7] and [12]). The given formulae are valid for spur and helical gears with tooth profiles in accordance with the basic rack standardized in ISO 53. They can also be used for teeth conjugate to other basic racks if the virtual contact ratio $\varepsilon_{\alpha n}$ is less than 2,5.

The load capacity determined on the basis of permissible bending stress is termed “tooth bending strength”. The results are in good agreement with other methods for the range, as indicated in the scope of ISO 6336-1.

If this scope does not apply, refer to ISO 6336-1:2019, Clause 4.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 53:1998, *Cylindrical gears for general and heavy engineering — Standard basic rack tooth profile*

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

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

ISO 4287:1997/Cor 1:1998, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters — TECHNICAL CORRIGENDUM 1*

ISO 4287:1997/Cor 2:2005, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters — TECHNICAL CORRIGENDUM 2*

ISO 4287:1997/Amd 1:2009, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters — AMENDMENT 1: Peak count number*

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

ISO 6336-1, *Calculation of load capacity of spur and helical gears — Part 1: Basic principles, introduction and general influence factors*

ISO 6336-5, *Calculation of load capacity of spur and helical gears — Part 5: Strength and quality of materials*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1122-1:1998 and ISO 6336-1 apply.

ISO and IEC maintain terminological databases for use in standardisation at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://electropedia.org/

3.2 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in ISO 1122-1:1998, ISO 6336-1 and Table 2 apply.

Table 2 — Abbreviated terms and symbols used in this document

Abbreviated terms	
Term	**Description**
Eh	material designation for case-hardened wrought steel
GG	material designation for grey cast iron
GGG	material designation for nodular cast iron (perlitic, bainitic, ferritic structure)
GTS	material designation for black malleable cast iron (perlitic structure)
IF	material designation for flame or induction hardened wrought special steel
M	point
NT	material designation for nitrided wrought steel, nitriding steel
NV	material designation for through-hardened wrought steel, nitrided, nitrocarburized
St	material designation for normalized base steel (σ_B < 800 N/mm^2)
V	material designation for through-hardened wrought special steel, alloy or carbon ($\sigma_B \geq$ 800 N/mm^2)
X	x-coordinate
Y	y-coordinate

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
a_0	manufacturing centre distance	mm
b	face width	mm
b_B	face width of one helix on a double helical gear	mm
d	diameter (without subscript, reference diameter[a])	mm
d_a	tip diameter[a]	mm
d_{an}	tip diameter of virtual gear	mm
d_b	base diameter	mm
d_{bn}	base diameter of virtual gear	mm
d_{b0}	base diameter of the tool	mm
d_{en}	outer single contact diameter of virtual gears	mm
d_n	reference diameter of virtual spur gear	mm
d_{Na}	active tip diameter	mm
d_w	pitch diameter	mm
d_0	reference diameter of the tool	mm
E	auxiliary value	mm
F_b	(nominal) load (normal to the line of contact or transverse to the plane of action)	N
F_{bn}	(nominal) load, normal to the line of contact	N
F_{bt}	(nominal) transverse load in the plane of action (base tangent plane)	N
F_{Rhigh}	load per unit facewidth of the higher loaded flank	N/mm
F_{Rlow}	load per unit facewidth of lower loaded flank	N/mm
F_t	(nominal) transverse tangential load at reference cylinder per mesh	N
F_w	(nominal) tangential load at the pitch cylinder	N
f_ε	load distribution influence factor	—
G	auxiliary value	—
H	auxiliary value	—
h_{aP}	addendum of basic rack of cylindrical gears	mm
h_{aP0}	addendum of tool	mm
h_{Fe}	bending moment arm for tooth root stress relevant to load application at the outer point of single pair tooth contact	mm
h_{fP}	dedendum of basic rack of cylindrical gears (ISO 53:1998 shall apply)	mm
h_t	tooth height	mm
K	distance of point M to the point of contact of the pitch circles	mm

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
K_A	application factor	—
$K_{F\alpha}$	transverse load factor (root stress)	—
$K_{F\beta}$	face load factor (root stress)	—
K_v	dynamic factor	—
K_γ	mesh load factor	—
L	auxiliary value	—
M	mean stress ratio	
m_n	normal module	mm
N_L	number of load cycles	—
p_{bn}	normal base pitch	mm
pr	protuberance of the tool	mm
q	material allowance for finish machining per flank	mm
q_s	notch parameter, $q_s = s_{Fn}/2\rho_F$	—
q_{sk}	notch parameter of the notched test piece	—
q_{sT}	notch parameter of the standard reference test gear	—
R	stress ratio	—
Rz	mean peak-to-valley roughness (ISO 4287:1997 including ISO 4287:1997/Cor 1:1998, ISO 4287:1997/Cor 2:2005, ISO 4287:1997/Amd 1:2009 and ISO 4288:1996 shall apply)	µm
Rz_k	mean peak-to-valley roughness of the notched, rough test piece	µm
Rz_T	mean peak-to-valley roughness in the filet of standard reference gears (see ISO/TR 10064-4)	µm
r	radius	mm
r_{a0}	tip radius of tool	mm
r_{b0}	base radius of the tool	mm
r_M	radius for the centre of the tool tip radius	mm
r_w	manufacturing pitch circle radius	mm
r_{w0}	manufacturing pitch circle radius of tool	mm
S	safety factor	—
S_F	safety factor for tooth breakage	—
$S_{F\,min}$	minimum required safety factor for tooth root stress	—
s_{Fn}	tooth root chord at the critical section	mm
s_{pr}	residual fillet undercut, $s_{pr} = pr - q$	mm
s_R	rim thickness	mm

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
T	auxiliary value	—
t_g	maximum depth of grinding notch	mm
u_0	manufacturing tooth ratio	—
X_M	x-coordinate of point M	mm
x	profile shift coefficient	—
$x_{E\,min}$	smallest generating profile shift	—
x_0	profile shift coefficient of the tool	—
Y_B	rim thickness factor, which adjusts the calculated tooth root stress for thin rimmed gears	—
Y_{DT}	deep tooth factor	—
Y_F	tooth form factor, for the influence on nominal tooth root stress with load applied at the outer point of single pair tooth contact	—
Y_M	mean stress influence factor (see Annex B)	—
Y_M	y-coordinate of point M	mm
Y_{Nk}	life factor for tooth root stress, relevant to the notched test piece	—
Y_{Np}	life factor for tooth root stress, relevant to the plain polished test piece	—
Y_{NT}	life factor for tooth root stress for reference test conditions	—
Y_R	tooth root surface factor (relevant to the plain polished test piece)	—
Y_{Rk}	surface factor	—
Y_{R0}	surface factor of the plain, polished test piece	—
$Y_{R\,rel\,k}$	relative roughness factor, the quotient of the gear tooth root surface factor of interest divided by the notch test piece factor, $Y_{R\,rel\,k} = Y_R/Y_{Rk}$	—
$Y_{R\,rel\,T}$	relative surface factor, the quotient of the gear tooth root surface factor of interest divided by the tooth root surface factor of the reference test gear, $Y_{R\,rel\,T} = Y_R/Y_{RT}$	—
Y_{RT}	tooth root surface factor of the reference test gears	—
Y_S	stress correction factor, for the conversion of the nominal tooth root stress, determined for application of load at the outer point of single pair tooth contact, to the local tooth root stress	—
Y_{Sg}	stress correction factor, relevant to the notched piece	—
Y_{Sk}	stress correction factor, relevant to the notched test piece	—
Y_{ST}	stress correction factor, relevant to the dimensions of the reference test gears	—
Y_X	size factor (tooth root)	—
Y_β	helix angle factor (tooth root)	—
Y_δ	notch sensitivity factor of the actual gear (relative to a polished test piece)	—

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
$Y_{\delta k}$	notch sensitivity factor of a notched test piece, relative to a smooth polished test piece	—
$Y_{\delta T}$	notch sensitivity factor of the standard reference test gear, relative to the smooth polished test piece	—
$Y_{\delta\ rel\ T}$	relative notch sensitivity factor, the quotient of the gear notch sensitivity factor of interest divided by the notch sensitivity factor of the standard reference test gear, $Y_{\delta\ rel\ T} = Y_{\delta} / Y_{\delta T}$	—
y	auxiliary value	° or rad
y'	auxiliary value	—
z	number of teeth [a]	—
z_n	virtual number of teeth of a helical gear	—
z_0	number of teeth of the tool	—
z_{0v}	equivalent number of teeth of the tool	—
α_{en}	profile angle at the outer point of a single pair tooth contact of virtual spur gears	°
α_{Fen}	load direction angle, relevant to direction of application of load at the outer point of single pair tooth contact of virtual spur gears	°
α_M	transverse pressure angle for the radius at the point M	°
α_n	normal pressure angle	°
α_w	working pressure angle	°
α_{w0}	operating pressure angle of the manufacturing pairing	°
α_x	transverse pressure angle of basic rack profile	°
β_b	base helix angle	°
γ	auxiliary angle	°
γ_e	auxiliary angle at the virtual gear	° or rad
$\Delta\alpha$	half angle of thickness at point M	°
Δh	auxiliary value	mm
$\Delta h'$	auxiliary value	mm
δ	auxiliary value	°
ε	contact ratio	—
ε_α	transverse contact ratio	—
$\varepsilon_{\alpha n}$	virtual contact ratio of the virtual spur gear	—
ε_β	overlap ratio	—
θ	tangential angle	° or rad
λ	auxiliary value	—
ξ	auxiliary value	—

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
ρ_{a0}	tool tip corner rounding	mm
ρ_F	tooth root radius at the critical section	mm
ρ_{fP}	tooth root fillet radius of the basic rack for cylindrical gears	mm
ρ_g	radius of grinding notch	mm
ρ'	slip layer thickness	mm
σ	normal stress	N/mm^2
σ_B	tensile strength	N/mm^2
σ_F	tooth root stress	N/mm^2
σ_{FE}	allowable stress number (bending), $\sigma_{FE} = \sigma_{F\,lim}\,Y_{ST}$	N/mm^2
σ_{FG}	tooth root stress limit	N/mm^2
$\sigma_{F\,lim}$	nominal stress number (bending)	N/mm^2
σ_{FP}	permissible bending stress	N/mm^2
$\sigma_{FP\,stat}$	permissible bending stress for the static stress	N/mm^2
$\sigma_{FP\,ref}$	permissible bending stress for the reference stress	N/mm^2
σ_{F0}	nominal tooth root stress	N/mm^2
$\sigma_{k\,lim}$	nominal notched-bar stress number (bending)	N/mm^2
$\sigma_{p\,lim}$	nominal plain-bar stress number (bending)	N/mm^2
σ_S	yield stress	N/mm^2
$\sigma_{0,2}$	proof stress (0,2 % permanent set)	N/mm^2
χ^*	relative stress gradient in the root of a notch	mm^{-1}
χ^*_K	relative stress gradient in the notch root of the test piece	mm^{-1}
χ^*_p	relative stress gradient in a smooth polished test piece	mm^{-1}
χ^*_T	relative stress gradient of the standard reference test gear	mm^{-1}
ψ	auxiliary angle	° or rad
ω_0	auxiliary angle	°

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

4 Tooth breakage and safety factors

Tooth breakage usually ends the service life of a transmission. Sometimes, the destruction of all gears in a transmission can be a consequence of the breakage of one tooth. In some instances, the transmission path between input and output shafts is broken. As a consequence, the chosen value of the safety factor S_F against tooth breakage should be larger than the safety factor against pitting.

General comments on the choice of the minimum safety factor can be found in ISO 6336-1:2019, 4.1.11. It is recommended that the manufacturer and the customer agree on the value of the minimum safety factor.

This document does not apply at stress levels above those permissible for 10^3 cycles, since stresses in this range may exceed the elastic limit of the gear tooth.

5 Basic formulae

5.1 General

The actual tooth root stress σ_F and the permissible (tooth root) bending stress σ_{FP} shall be calculated separately for the pinion and the wheel; σ_F shall be less than σ_{FP}.