INTERNATIONAL STANDARD

ISO 6336-1

Second edition
2006-09-01

Corrected version
2007-04-01

Calculation of load capacity of spur and helical gears —

Part 1:
Basic principles, introduction and general influence factors

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

Partie 1: Principes de base, introduction et facteurs généraux d'influence

Reference number
ISO 6336-1:2006(E)

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Published in Switzerland

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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 6336-1 was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

This second edition cancels and replaces the first edition (ISO 6336-1:1996), Clauses 6, 7 and 9 of which have been technically revised. It also incorporates the Amendments ISO 6336-1:1996/Cor.1:1998 and ISO 6336-1:1996/Cor.2:1999.

ISO 6336 consists of the following parts, under the general title *Calculation of load capacity of spur and helical gears*:

— *Part 1: Basic principles, introduction and general influence factors*

— *Part 2: Calculation of surface durability (pitting)*

— *Part 3: Calculation of tooth bending strength*

— *Part 5: Strength and quality of materials*

— *Part 6: Calculation of service life under variable load*

This corrected version incorporates the following corrections:

— the lines in Figure 17 have been corrected;

— Figure 19 has been replaced with the correct figure for the wheel blank factor;

— in Equation (90), C_R has been inserted;

— missing parentheses have been added in Equation (B.2);

— the cross-reference following Equation (D.9) has been changed to correspond to that Equation.

Introduction

This and the other parts of ISO 6336 provide a coherent system of procedures for the calculation of the load capacity of cylindrical involute gears with external or internal teeth. ISO 6336 is designed to facilitate the application of future knowledge and developments, also the exchange of information gained from experience.

Design considerations to prevent fractures emanating from stress raisers in the tooth flank, tip chipping and failures of the gear blank through the web or hub will need to be analyzed by general machine design methods.

Several methods for the calculation of load capacity, as well as for the calculation of various factors, are permitted (see 4.1.12). The directions in ISO 6336 are thus complex, but also flexible.

Included in the formulae are the major factors which are presently known to affect gear tooth pitting and fractures at the root fillet. The formulae are in a form that will permit the addition of new factors to reflect knowledge gained in the future.

Calculation of load capacity of spur and helical gears —

Part 1: Basic principles, introduction and general influence factors

1 Scope

This part of ISO 6336 presents the basic principles of, an introduction to, and the general influence factors for, the calculation of the load capacity of spur and helical gears. Together with ISO 6336-2, ISO 6336-3, ISO 6336-5 and ISO 6336-6, it provides a method by which different gear designs can be compared. It is not intended to assure the performance of assembled drive gear systems. It is not intended for use by the general engineering public. Instead, it is intended for use by the experienced gear designer who is capable of selecting reasonable values for the factors in these formulae based on knowledge of similar designs and awareness of the effects of the items discussed.

The formulae in ISO 6336 are intended to establish a uniformly acceptable method for calculating the pitting resistance and bending strength capacity of cylindrical gears with straight or helical involute teeth.

ISO 6336 includes procedures based on testing and theoretical studies such as those of Hirt [1], Strasser [2] and Brossmann [3]. The results of rating calculations made by following this method are in good agreement with previously accepted gear calculations methods (see References [4] to [8]) for normal working pressure angles up to 25° and reference helix angles up to 25°).

For larger pressure angles and larger helix angles, the trends of products $Y_F\,Y_S\,Y_\beta$ and, respectively, $Z_H\,Z_\varepsilon\,Z_\beta$ are not the same as those of some earlier methods. The user of ISO 6336 is cautioned that when the methods in ISO 6336 are used for other helix angles and pressure angles, the calculated results will need to be confirmed by experience.

The formulae in ISO 6336 are not applicable when any of the following conditions exist:

— spur or helical gears with transverse contact ratios less than 1,0;

— spur or helical gears with transverse contact ratios greater than 2,5;

— interference between tooth tips and root fillets;

— teeth are pointed;

— backlash is zero.

The rating formulae in ISO 6336 are not applicable to other types of gear tooth deterioration such as plastic yielding, scuffing, case crushing, welding and wear, and are not applicable under vibratory conditions where there may be an unpredictable profile breakdown. The bending strength formulae are applicable to fractures at the tooth fillet, but are not applicable to fractures on the tooth working surfaces, failure of the gear rim, or failures of the gear blank through web and hub. ISO 6336 does not apply to teeth finished by forging or sintering. It is not applicable to gears which have a poor contact pattern.

The procedures in ISO 6336 provide rating formulae for the calculation of load capacity, based on pitting and tooth root breakage. At pitch line velocities below 1 m/s the gear load capacity is often limited by abrasive wear (see other literature for information on the calculation for this).

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

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

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

ISO 6336-2, *Calculation of load capacity of spur and helical gears — Part 2: Calculation of surface durability (pitting)*

ISO 6336-3, *Calculation of load capacity of spur and helical gears — Part 3: Calculation of tooth bending strength*

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

ISO 6336-6, *Calculation of load capacity of spur and helical gears — Part 6: Calculation of service life under variable load*

3 Terms, definitions, symbols and abbreviated terms

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

NOTE Symbols are based on, and are extensions of, the symbols given in ISO 701 and ISO 1328-1. Only symbols for quantities used for the calculation of the particular factors treated in ISO 6336 are given, together with the preferred units.

Table 1 — Symbols used in ISO 6336-1, ISO 6336-2, ISO 6336-3 and ISO 6336-5

Symbol	Description	Unit
	Principal symbols and abbreviations	
A, B, C, D, E	points on path of contact (pinion root to pinion tip, regardless of whether pinion or wheel drives, only for geometrical considerations)	—
a	centre distance [a]	mm
α	pressure angle (without subscript, at reference cylinder)	°
B	total face width of double helical gear including gap width	mm
b	face width	mm
β	helix angle (without subscript, at reference cylinder)	°
C	constant, coefficient	—
	relief of tooth flank	µm
c	constant	—
γ	auxiliary angle	°
D	diameter (design)	mm
d	diameter (without subscript, reference diameter)	mm
δ	deflection	µm
E	modulus of elasticity	N/mm^2
Eh	material designation for case-hardened wrought steel	—
Eht	case depth, see ISO 6336-5	mm
e	auxiliary quantity	—
ε	contact ratio, overlap ratio, relative eccentricity (see Clause 7)	—
ζ	roll angle	°
F	composite and cumulative deviations	µm
	force or load	N
f	deviation, tooth deformation	µm
G	shear modulus	N/mm^2
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)	—
g	path of contact	mm
ϑ	temperature	°C
HB	Brinell hardness	—
HRC	Rockwell hardness (C scale)	—
HR 30N	Rockwell hardness (30 N scale) (see ISO 6336-5)	—
HV	Vickers hardness	—
HV 1	Vickers hardness at load F = 9,81 N (see ISO 6336-5)	—
HV 10	Vickers hardness at load F = 98,10 N (see ISO 6336-5)	—
h	tooth depth (without subscript, root circle to tip circle)	mm
η	effective dynamic viscosity of the oil wedge at the mean temperature of wedge	mPa s
IF	material designation for flame or induction hardened wrought special steel	—
i	transmission ratio	—
	bin	—
J	Jominy hardenability (see ISO 6336-5)	—
K	constant, factors concerning tooth load	—

Table 1 (*continued*)

Symbol	Description	Unit
L	lengths (design)	mm
l	bearing span	mm
Γ	parameter on the line of action	—
M	moment of a force	Nm
	mean stress ratio	—
ME	symbols identifying material and heat-treatment requirements (see ISO 6336-5)	—
MQ		—
ML		—
m	module	mm
	mass	kg
μ	coefficient of friction	—
N	number, exponent, resonance ratio	—
NT	material designation for nitrided wrought steel, nitriding steel	—
NV	material designation for through-hardened wrought steel, nitrided, nitrocarburized	—
n	rotational speed	s^{-1} or min^{-1}
	number of load cycles	
ν	Poisson's ratio	—
	kinematic viscosity of the oil	mm^2/s
P	transmitted power	kW
p	pitch	mm
	number of planet gears	—
	slope of the Woehler-damage line	—
q	auxiliary factor	—
	flexibility of pair of meshing teeth (see Clause 9)	(mm·µm)/N
	material allowance for finish machining (see ISO 6336-3)	mm
r	radius (without subscript, reference radius)	mm
ρ	radius of curvature	mm
	density (for steel, $\rho = 7{,}83 \times 10^{-6}$)	kg/mm^3
S	safety factor	—
St	material designation for normalized base steel ($\sigma_B < 800$ N/mm²)	—
s	tooth thickness, distance between mid-plane of pinion and the middle of the bearing span	mm
σ	normal stress	N/mm^2
T	torque	Nm
	tolerance	µm
τ	shear stress	N/mm^2
	angular pitch	mm
u	gear ratio $(z_2 / z_1) \geqslant 1$ [a]	—
U	Miner sum	—
V	material designation for through-hardened wrought special steel, alloy or carbon ($\sigma_B \geqslant 800$ N/mm²)	—
v	tangential velocity (without subscript, at the reference circle = tangential velocity at pitch circle)	m/s
w	specific load (per unit face width, F_t / b)	N/mm
ψ	auxiliary angle	°
x	profile shift coefficient	—

Table 1 (*continued*)

Symbol	Description	Unit
χ	running-in factor	—
Y	factor related to tooth root stress	—
y	running-in allowance (only with subscript α or β)	µm
Z	factor related to contact stress	—
z	number of teeth [a]	—
ω	angular velocity	rad/s
Subscripts to symbols		
—	reference values (without subscript)	
A	application	
	external shock loads	
a	addendum	
	tooth tip	
ann	annulus gear	
α	transverse contact	
	profile	
b	base circle	
	face width	
be	bearing	
β	helix	
	face width	
	crowning	
C	pitch point	
	profile and helix modification	
ca	case	
cal	calculated	
co	contact pattern	
γ	total (total value)	
D	speed transformation	
	reducing or increasing	
dyn	dynamic	
Δ	rough specimen	
E	elasticity of material	
	resonance	
e	outer limit of single pair tooth contact	
eff	effective value, real stress	
ε	contact ratio	
F	tooth root stress	
f	tooth root, dedendum	
G	geometry	
H	Hertzian stress (contact stress)	
i	internal	
	bin number	
k	values related to the notched test piece	

Table 1 (*continued*)

Symbol	Description
L	lubrication
lim	value of reference strength
M	mean stress influence
m	mean or average value (mean section)
ma	manufacturing
max	maximum value
min	minimum value
N	number (a specific number may be inserted after the subscript N in the life factor)
n	normal plane
	virtual spur gear of a helical gear
	number of revolutions
oil	oil
P	permissible value
	rack profile
p	pitch
	values related to the smooth polished test piece
par	parallel
pla	planet gear
R	roughness
r	radial
red	reduced
rel	relative
s	tooth thickness
	notch effect
sh	shaft
stat	static (load)
sun	sun pinion, sun gear
T	test gear
	values related to the standard reference test gear
t	transverse plane
th	theoretical
v	velocity
	losses
W	pairing of materials
w	working (this subscript may replace the prime)
X	dimension (absolute)
y	running-in
	any point on the tooth flank
z	sun
0	basic value
	tool
1	pinion
2	wheel

Table 1 (*continued*)

Symbol	Description	
1..9	general numbering	
I(II)	end relief	
	reference (nonreference) face	
′	single-flank (subscript w possible) single-pair tooth contact	
″	double-flank contact (simultaneous contact between working and non-working flanks)	
Combined symbols		**Unit**
α_{en}	form-factor pressure angle, pressure angle at the outer point of single pair tooth contact of virtual spur gears	°
α_n	normal pressure angle	°
α_t	transverse pressure angle	°
α'_t or α_{wt}	pressure angle at the pitch cylinder	°
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_{Pn}	normal pressure angle of the basic rack for cylindrical gears	°
B^*	constant (see equations in Clause 7)	—
b_{cal}	calculated face width	mm
b_{c0}	length of tooth bearing pattern at no load (contact marking)	mm
b_{red}	reduced face width (face width minus end reliefs)	mm
b_s	web thickness	mm
b_B	face width of one helix on a double helical gear	mm
$b_{I(II)}$	length of end relief	mm
β_b	base helix angle	°
β_e	form-factor helix angle, helix angle at the outer point of single tooth contact	°
C_a	tip relief	µm
C_{ay}	tip relief by running-in	µm
C_B	basic rack factor (same rack for pinion and wheel)	—
C_{B1}	basic rack factor (pinion)	—
C_{B2}	basic rack factor (wheel)	—
C_M	correction factor (see Clause 9)	—
C_R	gear blank factor (see Clause 9)	—
$C_{ZL,\ ZR,\ Zv}$	factors for determining lubricant film factors (see ISO 6336-2)	—
C_β	crowning height	µm
$C_{I(II)}$	end relief	µm
c_γ	mean value of mesh stiffness per unit face width	N/(mm·µm)
$c_{\gamma\alpha}$	mean value of mesh stiffness per unit face width (used for K_v, $K_{H\alpha}$, $K_{F\alpha}$)	N/(mm·µm)
$c_{\gamma\beta}$	mean value of mesh stiffness per unit face width (used for $K_{H\beta}$, $K_{F\beta}$)	N/(mm·µm)
c'	maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)
c'_{th}	theoretical single stiffness	N/(mm·µm)
D_{be}	bearing bore diameter (plain bearings)	mm
D_{sh}	journal diameter (plain bearings)	mm
d_a	tip diameter	mm
d_b	base diameter	mm
d_e	diameter of circle through outer point of single pair tooth contact	mm