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Calculation of load capacity of spur and helical gears —

Part 30: Calculation examples for the application of ISO 6336 parts 1,2,3,5

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

Partie 30: Exemples de calculs selon l'ISO 6336 parties 1, 2, 3 et 5

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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).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

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

Introduction

The ISO 6336 series 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.

— TS contain calculation methods that are still subject to further development.

— TR contain data that is informative, such as example calculations.

The procedures specified in ISO 6336-1 to ISO 6336-19 cover fatigue analyses for gear rating. The procedures described in ISO 6336-20 to ISO 6336-29 are predominantly related to the tribological behaviour of the lubricated flank surface contact. ISO 6336-30 to ISO 6336-39 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 ISO 6336 without referring to specific parts requires the use of only those parts that are designated as International Standards (see Table 1 for listing). When requesting further calculations, the relevant part or parts of ISO 6336 need to be specified. Use of a Technical Specification as acceptance criteria for a specific design needs to be agreed in advance between manufacturer and purchaser.

Table 1 — Overview of ISO 6336

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 6336-1, ISO 6336-2, ISO 6336-3 and, ISO 6336-5			X
Part 31: Calculation examples of micropitting load capacity (replaces: ISO/TR 15144-2)			X
NOTE At the time of publication of this document, some of the parts listed here were under development. Consult the ISO website.			

This document provides worked examples for the application of the calculation procedures defined in ISO 6336-1, ISO 6336-2, ISO 6336-3 and ISO 6336-5. The example calculations cover the application to spur, helical and double helical, external and internal cylindrical involute gears for both high speed and low speed operating conditions, determining the ISO safety factors against tooth flank pitting and tooth root bending strength for each gear set. The calculation procedures used are consistent with those presented in ISO 6336-1, ISO 6336-2, ISO 6336-3 and ISO 6336-5, unless qualifying comments are provided. Where qualifying comments have been included in this document, they reflect areas of the calculation procedures presented in the current standards where points of clarification are required or editorial errors have been identified. The changes defined within the qualifying comments will be implemented in future releases of ISO 6336-1, ISO 6336-2, ISO 6336-3 and ISO 6336-5. No additional calculations are presented here that are outside of the referenced documents.

Eight worked examples are presented with the necessary input data for each gear set provided at the beginning of the calculation. Calculation details are presented in full for one worked example, with all following examples having summarized results data presented in tabular format.

For all calculations in this document, the ISO accuracy grades according to ISO 1328-1:1995 are applied. Using the ISO tolerance classes of ISO 1328-1:2013 would lead to deviations of the calculation results.

Calculation of load capacity of spur and helical gears —

Part 30:
Calculation examples for the application of ISO 6336 parts 1,2,3,5

1 Scope

This document presents worked examples that apply exclusively the approximation methods for the determination of specific influential factors, such as the dynamic factor, K_v, and the load distributions factors $K_{H\alpha}$, $K_{H\beta}$, etc., where full analytical calculation procedures are provided within the referenced parts of ISO 6336.

Worked examples covering the more advanced analysis techniques and methods are outside the scope of this document.

The example calculations presented in this document are provided for guidance on the application of ISO 6336-1, ISO 6336-2, ISO 6336-3 and ISO 6336-5. Any of the values, safety factors or the data presented are not to be taken as recommended criteria for real gearing. Data presented within this document are for the purpose of aiding the application of the calculation procedures of ISO 6336-1, ISO 6336-2, ISO 6336-3 and ISO 6336-5.

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

ISO 6336 (all parts), *Calculation of load capacity of spur and helical gears*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1122-1 and ISO 6336 (all parts) apply.

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

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

— IEC Electropedia: available at https://www.electropedia.org/

3.2 Symbols and units

The units of length metre, millimetre and micrometre are chosen in accordance with common practice. The conversions of the units are already included in the given formulae.

Symbol	Description	Unit
a	centre distance	mm
B_1	constant	—
B_2	constant	—
B_f	non-dimensional parameter	—
B_K	non-dimensional parameter	—
B_P	non-dimensional parameter	—
b	face width (total face width if double helical)	mm
b_B	face width per helical if double helical (b/2)	mm
b_{eff}	contact face width	mm
C_a	tip relief	µm
C_B	basic rack factor	—
C_M	correction factor	—
C_R	gear blank factor	—
C_{v1}	constant	—
C_{v2}	constant	—
C_{v3}	constant	—
C_{v4}	constant	—
C_{v5}	constant	—
C_{v6}	constant	—
C_{v7}	constant	—
C_{ZL}	lubrication film factor exponent	—
C_{ZR}	roughness factor exponent	—
$c_{\gamma\alpha}$	mean value of mesh stiffness per unit face width	N/(mm·µm)
$c_{\gamma\beta}$	mean value of mesh stiffness per unit face width	N/(mm·µm)
c'	maximum tooth stiffness per unit face width of gear pair	N/(mm·µm)
c'_{th}	theoretical single stiffness	N/(mm·µm)
d_a	outside diameter	mm
d_{an}	virtual tip diameter	mm
d_{bn}	virtual base diameter	mm
d_{en}	virtual outer single tooth contact diameter	mm
d_m	mean tooth diameter	mm
d_n	virtual reference diameter	mm
d_w	working pitch diameter	mm
E	auxiliary value (for form factor)	—
$F_{\beta x}$	initial equivalent misalignment	µm
$F_{\beta y}$	effective equivalent misalignment	µm
$f_{f\alpha eff}$	effective profile deviation after run in	µm
F_M	mean transverse tangential load	N
$f_{f\alpha}$	profile form deviation (from ISO 1328-1:1995)	µm
$f_{H\beta}$	helix slope deviation (from ISO 1328-1:1995)	µm
f_{ma}	mesh misalignment	µm

Symbol	Description	Unit
f_{pb}	transverse base pitch deviation	µm
f_{pbeff}	effective single pitch deviation after run in	µm
f_{pt}	transverse pitch deviation (from ISO 1328-1:1995)	µm
f_{sh}	equivalent misalignment	µm
F_t	nominal tangential load	N
F_{tH}	determinant tangential load	N
G	auxiliary value (for form factor)	—
H	auxiliary value (for form factor)	—
h	tooth depth	mm
h_{Fe}	bending moment arm	mm
h_{fP}	basic rack dedendum coefficient	mm
h_K	tip chamfer	mm
K	constant	—
K_A	application factor	—
$K_{F\alpha}$	transverse load factor	—
$K_{F\beta}$	face load factor	—
$K_{H\alpha}$	transverse load factor	—
$K_{H\beta}$	face load factor	—
K_v	dynamic factor	—
k	number of teeth spanned	—
L	auxiliary notch parameter	—
m_n	normal module	mm
m_{red}	reduced gear pair mass per unit face width	kg/mm
N	resonance ratio	—
$n_{1,2}$	rotation speed of pinion (or wheel)	min^{-1}
n_{E1}	resonance speed	min^{-1}
N_F	exponent	—
N_L	number of load cycles	—
p_{bn}	virtual base pitch	mm
q	material allowance for finishing	mm
q_s	notch parameter	—
q_{sT}	notch parameter of standard reference test piece	—
q'	flexibility of pair of meshing teeth	(mm·µm)/N
Ra	arithmetic mean roughness value, $Ra = 1/6\ Rz$	µm
Rz	mean peak-to-valley surface roughness (as specified in ISO 4287 and ISO 4288)	µm
Rz_{10}	mean relative peak-to-valley roughness for gear pair	µm
S_F	safety factor for bending	—
s_{Fn}	tooth root normal chord	mm
S_H	safety factor for surface durability	—
s	bearing span offset	mm
s_{pr}	residual undercut	mm
$T_{1,2}$	nominal torque at pinion/wheel	Nm
v	tangential velocity	m/s
W_k	span measurement	mm

Symbol	Description	Unit
x	nominal profile shift coefficient	—
x_E	effective profile shift coefficient	—
Y_B	rim thickness factor	—
Y_{DT}	deep tooth factor	—
Y_F	form factor	—
Y_{NT}	life factor	—
Y_{RrelT}	relative surface factor	—
Y_S	stress correction factor	—
Y_{ST}	stress correction factor, relevant to the dimensions of the reference test gears	—
Y_X	size factor	—
y_α	running in allowance	µm
Y_β	helix angle factor	—
y_β	running in allowance	µm
$Y_{\delta relT}$	relative notch sensitivity factor for reference stress	—
y_f	running in allowance	µm
Z_B	single pair tooth contact factor	—
Z_β	helix angle factor	—
Z_D	single pair tooth contact factor	—
Z_E	elasticity factor	N/mm^2
Z_ε	contact ratio factor	—
Z_H	zone factor	—
Z_L	lubricant factor	—
z	number of teeth	—
z_n	virtual number of teeth	—
Z_{NT}	life factor	—
Z_R	roughness factor	—
Z_v	velocity factor	—
Z_W	work hardening factor	—
Z_X	size factor	—
α_n	normal pressure angle	°
α_{en}	virtual form factor pressure angle	°
α_{Fen}	virtual load direction angle	°
α_t	transverse pressure angle	°
α_{wt}	transverse working pressure angle	°
β	helix angle	°
ε_α	transverse contact ratio	—
$\varepsilon_{\alpha n}$	virtual contact ratio	—
ε_β	overlap ratio	—
ε_γ	total contact ratio	—
γ	auxiliary angle	°
ν_{40}	lubrication viscosity	mm^2/s
ρ	material density	kg/mm^3
ρ	radius of curvature	mm
ρ_F	radius of root fillet	mm
ρ_{fP}	root fillet radius of the basic rack for cylindrical gears	mm

Symbol	Description	Unit
ρ_{red}	relative radius of curvature	mm
ρ'	slip layer thickness	mm
θ	auxiliary value (for form factor)	rad
σ_{F0}	nominal tooth root stress	N/mm^2
σ_F	tooth root stress	N/mm^2
σ_{Flim}	allowable stress number (bending)	N/mm^2
σ_{FP}	permissible bending stress	N/mm^2
$\sigma_{FPlonglife}$	permissible bending stress (long life)	N/mm^2
σ_{FPref}	permissible bending stress (reference condition)	N/mm^2
σ_H	contact stress	N/mm^2
$\sigma_{H\,lim}$	allowable stress number (surface)	N/mm^2
σ_{H0}	nominal contact stress at pitch point	N/mm^2
σ_{HP}	permissible contact stress	N/mm^2
$\sigma_{HPlonglife}$	permissible contact stress (long life)	N/mm^2
σ_{HPref}	permissible contact stress (reference)	N/mm^2
χ^*	relative stress gradient in root of a notch	mm^{-1}
χ^*_P	stress gradient – smooth, polished test piece	mm^{-1}
χ^*_T	stress gradient for reference test piece	mm^{-1}
1	pinion	—
2	wheel	—
1..9	general numbering	—

4 Worked examples

4.1 General

This clause presents examples for the calculation of the safety factor for surface durability, S_H, and safety factor for tooth breakage, S_F. For all examples where various calculation methods are presented for the determination of specific influencing factors, the approximate methods detailed in the ISO 6336 series are applied. Where a specific method is used to calculate an influence parameter, the method used is denoted as a subscript to that factor (as defined in ISO 6336-1).

In the examples presented, the calculations based on the input data result in specific aspects of the rating procedure being invoked to highlight the influence of specific gear pair geometry, quality or application.

For example 1, the full calculation procedure is presented including the formulae. For all subsequent calculations, only the tabulated input and results data are provided.

In a number of areas, points of clarification of the procedure or specific criteria that differ slightly from the definitions provided in ISO 6336-1, ISO 6336-2 and ISO 6336-3 are incorporated within the example calculations. The points reflect the true intention of the procedures of ISO 6336-1, ISO 6336-2 and ISO 6336-3 and are defined in 4.2.

NOTE 1 The calculations and results presented were performed using computer-based procedures. If the calculations are performed manually, it is possible that small differences between the results can appear.

NOTE 2 In the presented results, all values for K factors are presented with rounding to two decimal places (X,XX); however, for the actual calculations, the results for each factor have been used with unrounded values.

4.2 Qualifying comments

4.2.1 Calculation of base pitch deviation, f_{pb}, and its application to the running in allowances

The value calculated for f_{pb} is by means of Formula (1), and is applied without rounding:

$$f_{pb} = f_{pt} \cdot \cos(\alpha_t) \tag{1}$$

where f_{pt} is provided by ISO 1328-1.

For the calculation of the transverse load factor, $K_{H\alpha}$, and running in allowance, y_α, the following logic is applied from ISO 6336-1.

The criteria defined in ISO 6336-1:2006, 8.3.1, footnote 12 are to be applied only to ISO 6336-1:2006, 8.3.1 for the calculation of $K_{H\alpha}$ and $K_{F\alpha}$. For the calculation of the running in allowance, y_α, as per ISO 6336-1:2006, 8.3.5, then footnote 12 should not be applied. f_{pb} should never be replaced with $f_{f\alpha}$ and the greater of the values f_{pb1} and f_{pb2} is to be used for ISO 6336-1:2006, Formula (78).

4.2.2 Calculation of mesh stiffness, c_γ

The calculation of mesh stiffness, c_γ, in accordance with method B of ISO 6336-1:2006, 9.3.2, is applied for all example calculations. For all c_γ calculations, the use of nominal profile shift coefficient, x, and nominal basic rack dedendum, h_{fP}, is applied. The generating profile shift coefficient, x_E, is not used, even where x_E is used for other strength calculations associated with the tooth root (e.g. example 7).

4.2.3 Application of lubricant film Z_L, Z_V and Z_R, hardness Z_W and size Z_X influence factors

According to the ISO 6336 series, the permissible contact stress numbers for static and reference condition, including all relevant influence factors as defined, need to be calculated. For limited life, linear interpolation on a log–log scale, following the procedure of Z_{NT}, between these two values needs to be applied. Additional interpolation of Z_L, Z_V and Z_R and Z_W, Z_X does not apply.

4.2.4 Application of work hardening factor, Z_W

In example 5, where a surface-hardened pinion is used with a through-hardened wheel, the calculation for Z_W is invoked and applied separately to the pinion and wheel, i.e. Z_{W1} = 1,0 for hard pinion and Z_{W2} is calculated in accordance with ISO 6336-2:2006, 13.2. This is due to the fact that only the softer member benefits from the work hardening effect. For all other cases where both gears are either through-hardened or surface-hardened, then $Z_{W1,2}$ = 1 for both pinion and wheel.

4.2.5 Determination of *Rz*

The determination of *Rz* from the as specified *Ra* values is determined by the approximation suggested in ISO 6336-2:2006, 12.3.1.3.1, footnote 3, where *Rz* = 6 *Ra*.

4.2.6 Face width for calculations involving double helical gears

For calculations involving double helical gears (such as example 7), and for the application of ISO 6336-2:2006, Formula (35) the use of b_B is to be used in place of b.

4.2.7 Calculation of ε_β for double helical gears

For the calculation of ε_β for double helical gears, the value should apply for only one helix. For example, the value for face width, b, should be replaced with b_B.

4.2.8 Calculation of $f_{H\beta 5}$ *and* $f_{H\beta}$

The calculation of $f_{H\beta 5}$ for use in the determination of the initial equivalent misalignment, $F_{\beta x}$, in ISO 6336-1:2006, 7.5.2.3 is performed in accordance with ISO 1328-1 for accuracy grade 5 with the as required rounding applied.

4.2.9 Helix tolerance $f_{H\beta 5}$ *and* $f_{H\beta}$ for double helical gears

When calculating the helix deviation value $f_{H\beta 5}$ and $f_{H\beta}$ for double helical gears, the face width of one helix should be used, i.e. b_B.

4.2.10 Calculation of root diameter, d_f

For all calculations presented within this document, the calculation of the root diameter, d_f, is performed with the nominal profile shift coefficient, x, and not the effective profile shift coefficient, x_E.

4.2.11 Amendment to ISO 6336-3:2006, Formula (10) auxiliary value, E

In ISO 6336-3:2006, Formula (10), the symbol ρ_{fp} should be replaced with ρ_{fpv}.

4.2.12 Calculations for internal gears

For all calculations involving internal gears (example 6), the input data uses negative values for diameters as defined in ISO 6336 series; however, it should be noted that this is different from the terminology of ISO 21771, which uses positive values.

4.3 Example 1: Single helical case carburized gear pair

For example 1, input values and output values are given in Tables 2 and 3, respectively.

A full calculation description is provided in Annex A.

Table 2 — Example 1 input values

Type	Description	Unit	Symbol	Pinion	Wheel
Geometry	Number of teeth	—	z	17	103
	Normal module	mm	m_n	8,00	
	Normal pressure angle	—	α	20,00	
	Helix angle	—	β	15,80	
	Hand of helix	—	—	Left	Right
	Face width (total)	mm	b	100,00	100,00
	Gap width	mm	—	0	0
	Edge chamfer	mm	—	0,00	0,00
	Contact face width (total)	mm	b_{eff}	100,00	
	Centre distance	mm	a	500,00	
	Span measurement	mm	W_k	38,196	307,943
	Number of teeth spanned	—	k	2	13
	Dimension between balls	mm	M_{dK}	—	—
	Ball diameter	mm	D_M	—	—
	Nominal profile shift coefficient	—	x	0,145	0,000
	Generating profile shift coefficient (ref only)	—	x_E	(0,118)	(−0,027)
	Outside diameter	mm	d_a	159,66	872,35
	Basic rack dedendum coefficient	—	h_{fP}/m_n	1,400	1,400
	Tip chamfer	mm		0,00	0,00
	Basic rack fillet root radius coefficient	—	ρ_{fP}/m_n	0,39	0,39
	As cut basic rack undercut	mm	pr	0,00	0,00
	Material allowance for finishing	mm	q	0,00	0,00
	Residual undercut (calculated - p_r-q)	mm	s_{pr}	0,00	0,00
	Pinion cutter number of teeth	—	z_0	—	—
	Pinion cutter profile shift (ref)	—	x_0	—	—
	Flank finishing process	—	—	As cut	As cut
	Root finishing process	—	—	As cut	As cut
	Profile shift coefficient used for calculations	—	—	Nominal (x)	Nominal (x)
	Tip relief	µm	C_a	70	
Quality	ISO accuracy grade	—	—	5	5
	Single pitch deviation	µm	f_{pt}	8,0	9,5
	Profile form deviation	µm	$f_{f\alpha}$	10,0	12,0
	Helix slope deviation	µm	$f_{H\beta}$	8,5	9,5
	Surface roughness – flank Ra (Rz)	µm	—	1,0 (6,0)	1,0 (6,0)
	Surface roughness – fillet Ra (Rz)	µm	—	3,0 (18,0)	3,0 (18,0)

Table 2 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Material	Material	—	—	Eh	Eh
	Material quality	—	—	MQ	MQ
	Case hardness	—	—	60 HRC	60 HRC
	Core hardness	—	—	30 HRC	30 HRC
	Young's modulus	N/mm^2	E	206 000	206 000
	Poisson's ratio	—	ν	0,3	0,3
	Yield/proof stress	N/mm^2	$\sigma_S/\sigma_{0.2}$	—	—
	Shot peen	—	—	No	No
	Limited pitting allowable	—	—	No	No
Application	Application factor	—	$K_{A\text{-}A}$	1,00	
	Reverse bending	—	—	No	No
	Favourable contact position	—		No	No
	Helix modification (ISO 6336-1:2006, Table 8)	—	—	None (No. 1)	
	Dynamic factor, K_v, calculation method	—	—	Method B	
	Face load distribution factor, $K_{H\beta}$ and $K_{F\beta}$, calculation method	—	—	Method C	
	Number of meshes	—	N_M	1	1
	Gear blank type	—	—	Solid	Solid
	Web thickness	mm	b_s	—	—
	Inside diameter	mm	—	—	—
	Number of webs	—	—	—	—
	Arrangement (ISO 6336-1:2006, Figure 13)	—	—	a	
	Bearing span	mm	l	125,00	—
	Bearing span offset	mm	s	0,00	—
	External shaft diameter	mm	d_{sh}	100,00	—
	Internal shaft diameter	mm	d_{shi}	0,00	—
	Equivalent misalignment	µm	f_{sh}	As Formula (57)	
	Mesh misalignment	µm	f_{ma}	As Formula (64)	
	Minimum safety factor pitting	—	$S_{H\,min}$	1,00	
	Minimum safety factor tooth breakage	—	$S_{F\,min}$	1,00	
	Lubrication viscosity	mm^2/s	ν_{40}	320	
Load	Torque	kNm	T_1	9,000	
	Speed	rpm	n_1	360,0	
	Required life	hours	—	50 000	
	Life factor for contact stress, Z_{NT}, at 10^{10} cycles	—	—	0,85	0,85
	Life factor for tooth root stress, Y_{NT}, at 10^{10} cycles	—	—	0,85	0,85