TECHNICAL REPORT

ISO/TR 6336-30

First edition
2017-11

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

Reference number
ISO/TR 6336-30:2017(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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.

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 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

Table 3 — Example 1 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	141,34	856,35
d_a	Tip diameter	mm	159,66	872,35
d_b	Base circle diameter	mm	132,20	800,97
d_f	Root diameter (based on x)	mm	121,26	833,96
d_{Ff}	Root form diameter (based on x)	mm	132,29	839,46
d_{Nf}	Start of active profile diameter	mm	132,92	845,23
d_w	Working pitch diameter	mm	141,67	858,33
F_t	Tangential tooth load	N	127 352	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,00	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,13	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,00	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	1,16	
$K_{v\text{-B}}$	Dynamic factor	—	1,00	
S_F	Tooth root breakage safety factor	—	1,86	1,98
S_H	Pitting safety factor	—	1,03	1,09
v	Pitch line velocity	m/s	2,67	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,56	1,34
Y_{NT}	Life factor for tooth root stress	—	0,89	0,92
Y_{RrelT}	Relative surface factor	—	0,96	0,96
Y_S	Stress correction factor	—	1,82	2,07
Y_{ST}	Stress correction factor for reference gears	—	2,00	
YX	Size factor	—	0,97	0,97
$Y_{\delta relT}$	Relative notch sensitivity factor	—	0,99	1,00
Z_B	Single pair tooth contact factor, pinion	—	1,00	
Z_β	Helix angle factor (pitting)	—	1,02	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N/mm^2}$	189,81	
Z_ε	Contact ratio factor	—	0,80	
Z_H	Zone factor	—	2,40	
Z_L	Lubrication factor	—	1,05	
Z_{NT}	Life factor for pitting stress	—	0,91	0,96
Z_R	Roughness factor	—	0,97	
Z_v	Velocity factor	—	0,97	
Z_W	Work hardening factor	—	1,00	1,00
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,55	
ε_β	Overlap ratio	—	1,08	
ε_γ	Total contact ratio	—	2,63	
σ_{F0}	Nominal tooth root stress	N/mm^2	393	383
σ_F	Tooth root stress	N/mm^2	444	434
$\sigma_{F\,lim}$	Limiting tooth root stress	N/mm^2	500	500

Table 3 *(continued)*

Symbol	Description	Unit	Pinion	Gear
σ_{FP}	Permissible tooth root stress	N/mm^2	825	861
σ_H	Contact stress	N/mm^2	1 302	1 302
$\sigma_{H\,lim}$	Limiting contact stress	N/mm^2	1 500	1 500
σ_{H0}	Nominal contact stress	N/mm^2	1 207	
σ_{HP}	Permissible contact stress	N/mm^2	1 338	1 415
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-}B}$, $K_{H\alpha\text{-}B}$, $K_{F\alpha\text{-}B}$)	N/(mm·µm)	17,5	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	12,4	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	0,067	
N	Resonance ratio	—	0,04	
$K_{H\beta\text{-}C}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-}C}$, $K_{F\beta\text{-}C}$)	N/(mm·µm)	14,8	
f_{sh0}	Shaft deformation under specific load	µm	0,012	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	32,3	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	27,5	
y_α	Running-in allowance for a gear pair	µm	0,668	
y_β	Running-in allowance (equivalent misalignment)	µm	4,9	
f_{pb}	Transverse base pitch deviation	µm	8,9	
Eq for $F_{\beta x}$	—		52	
$f_{H\beta 5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	9,5	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	14,7	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	12,7	

4.4 Example 2: Single helical through-hardened gear pair

For example 2, input values are given in Tables 4 and 5.

Table 4 — Example 2 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	—	—	Lefts	Right
	Face width (total)	mm	b	100,00	100,00
	Gap width	mm	—	—	—
	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	1,250	1,250
	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 - *pr*-*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	—	—	8	6
	Single pitch deviation	µm	f_{pt}	23,0	14,0
	Profile form deviation	µm	$f_{f\alpha}$	28,0	17,0
	Helix slope deviation	µm	$f_{H\beta}$	25,0	14,0
	Surface roughness – flank *Ra* (*Rz*)	µm	—	3,0 (18,0)	3,0 (18,0)
	Surface roughness – fillet *Ra* (*Rz*)	µm	—	3,0 (18,0)	3,0 (18,0)

Table 4 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Material	Material	—	—	V	V
	Material quality	—	—	MQ	MQ
	Case hardness	—	—	310 HV	260 HV
	Core hardness	—	—	—	—
	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	$\sigma_S/\sigma_{0,2}$	500,0	500,0
	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}	15,0	
	Mesh misalignment	µm	f_{ma}	5,0	
	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	1,000	
	Speed	rpm	n_1	360,0	
	Required life	hours	—	100 00	
	Life factor for contact stress, Y_{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

Table 5 — Example 2 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	141,34	856,35
d_a	Tip diameter	mm	159,66	872,35
d_b	Base circle diameter	mm	132,20	800,97
d_f (based on x)	Root diameter	mm	123,66	836,36
d_{Ff} (based on x)	Root form diameter	mm	132,71	841,51
d_{Nf}	Start of active profile diameter	mm	132,92	845,23
d_w	Working pitch diameter	mm	141,67	858,33
F_t	Tangential tooth load	N	14 150	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,65	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,61	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,65	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	1,78	
$K_{v\text{-B}}$	Dynamic factor	—	1,04	
S_F	Tooth root breakage safety factor	—	4,77	4,60
S_H	Pitting safety factor	—	0,86	0,85
v	Pitch line velocity	m/s	2,67	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,36	1,27
Y_{NT}	Life factor for tooth root stress	—	0,92	0,95
Y_{RrelT}	Relative surface factor	—	0,96	0,96
Y_S	Stress correction factor	—	1,97	2,16
Y_{ST}	Stress correction factor for reference gears	—	2,00	
Y_X	Size factor	—	0,98	0,98
$Y_{\delta relT}$	Relative notch sensitivity factor	—	0,98	1,00
Z_B	Single pair tooth contact factor, pinion	—	1,00	
Z_β	Helix angle factor (pitting)	—	1,02	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N/mm^2}$	189,81	
Z_ε	Contact ratio factor	—	0,80	
Z_H	Zone factor	—	2,40	
Z_L	Lubrication factor	—	1,09	
Z_{NT}	Life factor for pitting stress	—	0,96	1,03
Z_R	Roughness factor	—	0,79	
Z_v	Velocity factor	—	0,93	
Z_W	Work hardening factor	—	1,00	1,00
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,55	
ε_β	Overlap ratio	—	1,08	
ε_γ	Total contact ratio	—	2,63	
σ_{F0}	Nominal tooth root stress	N/mm^2	41	42
σ_F	Tooth root stress	N/mm^2	114	116
$\sigma_{F\,lim}$	Limiting tooth root stress	N/mm^2	319	298

Table 5 *(continued)*

Symbol	Description	Unit	Pinion	Gear
σ_{FP}	Permissible tooth root stress	N/mm²	545	535
σ_{H}	Contact stress	N/mm²	703	703
$\sigma_{H\,lim}$	Limiting contact stress	N/mm²	780	714
σ_{H0}	Nominal contact stress	N/mm²	402	
σ_{HP}	Permissible contact stress	N/mm²	603	599
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-}B}$, $K_{H\alpha\text{-}B}$, $K_{F\alpha\text{-}B}$)	N/(mm·µm)	18,9	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	13,4	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	0,069	
N	Resonance ratio	—	0,04	
$K_{H\beta\text{-}C}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-}C}$, $K_{F\beta\text{-}C}$)	N/(mm·µm)	16,1	
f_{sh0}	Shaft deformation under specific load	µm	—	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	25,0	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	14,2	
y_{α}	Running-in allowance for a gear pair	µm	4,61	
y_{β}	Running-in allowance (equivalent misalignment)	µm	10,7	
f_{pb}	Transverse base pitch deviation	µm	—	
Eq for $F_{\beta x}$	—		52	
$f_{H\beta 5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	—	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	—	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	—	

4.5 Example 3: Spur through-hardened gear pair

For example 3, input values and output values are given in Tables 6 and 7, respectively.

Table 6 — Example 3 input values

Type	Description	Unit	Symbol	Pinion	Wheel
Geometry	Number of teeth	—	z	17	108
	Normal module	mm	m_n	8,00	
	Normal pressure angle	—	α	20,00	
	Helix angle	—	β	0,00	
	Hand of helix	—	—	Left	Right
	Face width (total)	mm	b	100,00	100,00
	Gap width	mm	—	0,00	0,00
	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	37,728	283,000
	Number of teeth spanned	—	k	2	12
	Dimension between balls	mm	M_{dK}	—	—
	Ball diameter	mm	D_M	—	—
	Nominal profile shift coefficient	—	x	0,100	−0,100
	Generating profile shift coefficient (ref only)	—	x_E	(0,073)	(−0,127)
	Outside diameter	mm	d_a	153,60	878,40
	Basic rack dedendum coefficient	—	h_{fP}/m_n	1,250	1,250
	Tip chamfer	mm	—	0,00	0,00
	Basic rack fillet root radius coefficient	—	ρ_{fP}/m_n	0,45	0,40
	As cut basic rack undercut	mm	pr	0,000	0,000
	Material allowance for finishing	mm	q	0,000	0,000
	Residual undercut (calculated - *pr-q*)	mm	s_{pr}	0,000	0,000
	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	—	—	8	6
	Single pitch deviation	µm	f_{pt}	23,0	14,0
	Profile form deviation	µm	$f_{f\alpha}$	28,0	17,0
	Helix slope deviation	µm	$f_{H\beta}$	25,0	14,0
	Surface roughness – flank *Ra* (*Rz*)	µm	—	3,0 (18,0)	3,0 (18,0)
	Surface roughness – fillet *Ra* (*Rz*)	µm	—	3,0 (18,0)	3,0 (18,0)

Table 6 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Material	Material	—	—	V	V
	Material quality	—	—	MQ	MQ
	Case hardness	—	—	310 HV	260 HV
	Core hardness	—	—	—	—
	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	$\sigma_S/\sigma_{0,2}$	500,0	500,0
	Shot peen	—	—	No	No
	Limited pitting allowable	—	—	No	No
Application	Application factor	—	$K_{A\text{-}A}$	1,000	
	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	100,0	—
	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	1,000	
	Speed	rpm	n_1	360,0	
	Required life	hours	—	10 000	
	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

Table 7 — Example 3 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	136,00	864,00
d_a	Tip diameter	mm	153,60	878,40
d_b	Base circle diameter	mm	127,80	811,89
d_f (based on x)	Root diameter	mm	117,60	842,40
d_{Ff} (based on x)	Root form diameter	mm	127,97	847,96
d_{Nf}	Start of active profile diameter	mm	127,98	851,54
d_w	Working pitch diameter	mm	136,00	864,00
F_t	Tangential tooth load	N	14706	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,26	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,76	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,26	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	1,99	
$K_{v\text{-B}}$	Dynamic factor	—	1,05	
S_F	Tooth root breakage safety factor	—	4,77	4,62
S_H	Pitting safety factor	—	0,73	0,79
v	Pitch line velocity	m/s	2,56	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,43	1,29
Y_{NT}	Life factor for tooth root stress	—	0,92	0,95
Y_{RrelT}	Relative surface factor	—	0,96	0,96
Y_S	Stress correction factor	—	1,86	2,09
Y_{ST}	Stress correction factor for reference gears	—	2,00	
Y_X	Size factor	—	0,98	0,98
$Y_{\delta relT}$	Relative notch sensitivity factor	—	0,98	0,99
Z_B	Single pair tooth contact factor, pinion	—	1,09	
Z_β	Helix angle factor (pitting)	—	1,00	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N/mm^2}$	189,81	
Z_ε	Contact ratio factor	—	0,88	
Z_H	Zone factor	—	2,49	
Z_L	Lubrication factor	—	1,09	
Z_{NT}	Life factor for pitting stress	—	0,96	1,03
Z_R	Roughness factor	—	0,79	
Z_v	Velocity factor	—	0,93	
Z_W	Work hardening factor	—	1,00	1,00
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,66	
ε_β	Overlap ratio	—	0,00	
ε_γ	Total contact ratio	—	1,66	
σ_{F0}	Nominal tooth root stress	N/mm^2	49	50
σ_F	Tooth root stress	N/mm^2	113	115
$\sigma_{F\,lim}$	Limiting tooth root stress	N/mm^2	319	298

Table 7 *(continued)*

Symbol	Description	Unit	Pinion	Gear
σ_{FP}	Permissible tooth root stress	N/mm^2	541	533
σ_H	Contact stress	N/mm^2	827	758
$\sigma_{H\,lim}$	Limiting contact stress	N/mm^2	780	714
σ_{H0}	Nominal contact stress	N/mm^2	468	
σ_{HP}	Permissible contact stress	N/mm^2	600	599
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-}B}$, $K_{H\alpha\text{-}B}$, $K_{F\alpha\text{-}B}$)	N/(mm·µm)	20,1	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	13,5	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	0,062	
N	Resonance ratio	—	0,04	
$K_{H\beta\text{-}C}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-}C}$, $K_{F\beta\text{-}C}$)	N/(mm·µm)	17,1	
f_{sh0}	Shaft deformation under specific load	µm	0,012	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	31,2	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	17,8	
y_α	Running-in allowance for a gear pair	µm	4,63	
y_β	Running-in allowance (equivalent misalignment)	µm	13,4	
f_{pb}	Transverse base pitch deviation	µm	21,6	
Eq for $F_{\beta x}$	—		52	
$f_{H\beta 5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	9,5	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	1,9	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	28,7	

4.6 Example 4: Spur case carburized gear pair

For example 4, input values and output values are given in Tables 8 and 9, respectively.

Table 8 — Example 4 input values

Type	Description	Unit	Symbol	Pinion	Wheel
Geometry	Number of teeth	—	z	17	108
	Normal module	mm	m_n	8,00	
	Normal pressure angle	—	α	20,00	
	Helix angle	—	β	0,00	
	Hand of helix	—	—	Left	Right
	Face width (total)	mm	b	100,00	100,00
	Gap width	mm	—	0,00	0,00
	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	37,728	283,000
	Number of teeth spanned	—	k	2	12
	Dimension between balls	mm	M_{dK}	—	—
	Ball diameter	mm	D_M	—	—
	Nominal profile shift coefficient	—	x	0,100	−0,100
	Generating profile shift coefficient (ref only)	—	x_E	(0,073)	(−0,127)
	Outside diameter	mm	d_a	154,60	878,40
	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	0,000	0,000
	Material allowance for finishing	mm	q	0,000	0,000
	Residual undercut (calculated - *pr-q*)	mm	s_{pr}	0,000	0,000
	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 8 *(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	—	$K_{A\text{-}A}$	1,000	
	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	100,0	—
	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

Table 9 — Example 4 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	136,00	864,00
d_a	Tip diameter	mm	153,60	878,40
d_b	Base circle diameter	mm	127,80	811,89
d_f	Root diameter (based on x)	mm	115,20	840,00
d_{Ff}	Root form diameter (based on x)	mm	127,80	845,87
d_{Nf}	Start of active profile diameter	mm	127,98	851,00
d_w	Working pitch diameter	mm	136,00	864,00
F_t	Tangential tooth load	N	132353	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,00	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,14	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,00	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	1,18	
$K_{v\text{-B}}$	Dynamic factor	—	1,01	
S_F	Tooth root breakage safety factor	—	1,46	1,68
S_H	Pitting safety factor	—	0,82	0,93
v	Pitch line velocity	m/s	2,56	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,69	1,32
Y_{NT}	Life factor for tooth root stress	—	0,89	0,92
Y_{RrelT}	Relative surface factor	—	0,96	0,96
Y_S	Stress correction factor	—	1,75	2,04
Y_{ST}	Stress correction factor for reference gears	—	2,00	
Y_X	Size factor	—	0,97	0,97
$Y_{\delta relT}$	Relative notch sensitivity factor	—	0,99	1,00
Z_B	Single pair tooth contact factor, pinion	—	1,07	
Z_β	Helix angle factor (pitting)	—	1,00	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N/mm^2}$	189,81	
Z_ε	Contact ratio factor	—	0,88	
Z_H	Zone factor	—	2,49	
Z_L	Lubrication factor	—	1,05	
Z_{NT}	Life factor for pitting stress	—	0,91	0,96
Z_R	Roughness factor	—	0,96	
Z_v	Velocity factor	—	0,97	
Z_W	Work hardening factor	—	1,00	1,00
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,70	
ε_β	Overlap ratio	—	0,00	
ε_γ	Total contact ratio	—	1,70	
σ_{F0}	Nominal tooth root stress	N/mm^2	490	446
σ_F	Tooth root stress	N/mm^2	562	512
$\sigma_{F\,lim}$	Limiting tooth root stress	N/mm^2	500	500

Table 9 *(continued)*

Symbol	Description	Unit	Pinion	Gear
σ_{FP}	Permissible tooth root stress	N/mm^2	823	860
σ_H	Contact stress	N/mm^2	1 620	1 515
$\sigma_{H\,lim}$	Limiting contact stress	N/mm^2	1 500	1 500
σ_{H0}	Nominal contact stress	N/mm^2	1 392	
σ_{HP}	Permissible contact stress	N/mm^2	1 335	1 412
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-B}}$, $K_{H\alpha\text{-B}}$, $K_{F\alpha\text{-B}}$)	N/(mm·µm)	18,9	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	12,4	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	0,061	
N	Resonance ratio	—	0,04	
$K_{H\beta\text{-C}}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-C}}$, $K_{F\beta\text{-C}}$)	N/(mm·µm)	16,1	
f_{sh0}	Shaft deformation under specific load	µm	0,012	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	34,7	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	29,5	
y_α	Running-in allowance for a gear pair	µm	0,67	
y_β	Running-in allowance (equivalent misalignment)	µm	5,2	
f_{pb}	Transverse base pitch deviation	µm	8,9	
Eq for $F_{\beta x}$	—		52	
$f_{H\beta5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	9,5	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	16,5	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	12,7	

4.7 Example 5: Spur gear pair with an induction hardened pinion and through-hardened cast gear

For example 5, input values and output values are given in Tables 10 and 11, respectively.

Table 10 — Example 5 input values

Type	Description	Unit	Symbol	Pinion	Wheel
Geometry	Number of teeth	—	z	27	192
	Normal module	mm	m_n	32,00	
	Normal pressure angle	—	α	20,00	
	Helix angle	—	β	0,00	
	Hand of helix	—	—	—	—
	Face width (total)	mm	b	500,00	500,00
	Gap width	mm	—	0,00	0,00
	Edge chamfer	mm	—	0,00	0,00
	Contact face width (total)	mm	b_{eff}	500,00	
	Centre distance	mm	a	3 504,00	
	Span measurement	mm	W_k	247,771	2 022,148
	Number of teeth spanned	—	k	3	21
	Dimension between balls	mm	M_{dK}	—	—
	Ball diameter	mm	D_M	—	—
	Nominal profile shift coefficient	—	x	0,000	0,000
	Generating profile shift coefficient (ref only)	—	x_E	(−0,023)	(−0,023)
	Outside diameter	mm	d_a	928,00	6 208,00
	Basic rack dedendum coefficient	—	h_{fP}/m_n	1,250	1,250
	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	0,000	0,000
	Material allowance for finishing	mm	q	0,000	0,000
	Residual undercut (calculated - *pr-q*)	mm	s_{pr}	0,000	0,000
	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	0	
Quality	ISO accuracy grade	—	—	6	9
	Single pitch deviation	µm	f_{pt}	24,0	94,0
	Base pitch deviation	µm	f_{pb}	—	—
	Profile form deviation	µm	$f_{f\alpha}$	27,0	115,0
	Helix slope deviation	µm	$f_{H\beta}$	21,0	76,0
	Surface roughness – flank *Ra* (*Rz*)	µm	—	2,5 (15,0)	3,0 (18,0)
	Surface roughness – fillet *Ra* (*Rz*)	µm	—	3,0 (18,0)	3,0 (18,0)

Table 10 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Material	Material	—	—	IF	St (cast)
	Material quality	—	—	ML	MQ
	Case hardness	—	—	550 HV	200 HBW
	Core hardness	—	—	166 HV	
	Young's modulus	N/mm^2	E	206 000	202 000
	Poisson's ratio	—	ν	0,3	0,3
	Yield/proof stress	N/mm^2	$\sigma_S/\sigma_{0,2}$		400,0
	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	1 000,00	—
	Bearing span offset	mm	s	0,00	—
	External shaft diameter	mm	d_{sh}	400,00	—
	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}	160	
Load	Torque	kNm	T_1	120,000	
	Speed	rpm	n_1	200,0	
	Required life	hours	—	25 000	
	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

Table 11 — Example 5 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	864,00	6 144,00
d_a	Tip diameter	mm	928,00	6 208,00
d_b	Base circle diameter	mm	811,89	5 773,47
d_f	Root diameter (based on x)	mm	784,00	6 064,00
d_{Ff}	Root form diameter (based on x)	mm	819,26	6 082,93
d_{Nf}	Start of active profile diameter	mm	820,02	6 093,07
d_w	Working pitch diameter	mm	864,00	6 144,00
F_t	Tangential tooth load	N	277 778	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,45	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,49	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,34	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	1,59	
$K_{v\text{-B}}$	Dynamic factor	—	1,30	
S_F	Tooth root breakage safety factor	—	2,77	1,56
S_H	Pitting safety factor	—	1,36	0,52
v	Pitch line velocity	m/s	9,05	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,28	1,12
Y_{NT}	Life factor for tooth root stress	—	0,91	0,95
Y_{RrelT}	Relative surface factor	—	0,96	0,98
Y_S	Stress correction factor	—	1,97	2,33
Y_{ST}	Stress correction factor for reference gears	—	2,00	
Y_X	Size factor	—	0,80	0,85
$Y_{\delta relT}$	Relative notch sensitivity factor	—	0,99	1,00
Z_B	Single pair tooth contact factor, pinion	—	1,06	
Z_β	Helix angle factor (pitting)	—	1,00	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N/mm^2}$	188,88	
Z_ε	Contact ratio factor	—	0,86	
Z_H	Zone factor	—	2,49	
Z_L	Lubrication factor	—	0,99	
Z_{NT}	Life factor for pitting stress	—	0,95	1,01
Z_R	Roughness factor	—	0,88	
Z_v	Velocity factor	—	0,99	
Z_W	Work hardening factor	—	1,00	1,05
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,77	
ε_β	Overlap ratio	—	0,00	
ε_γ	Total contact ratio	—	1,77	
σ_{F0}	Nominal tooth root stress	N/mm^2	44	45
σ_F	Tooth root stress	N/mm^2	123	126
$\sigma_{F\,lim}$	Limiting tooth root stress	N/mm^2	244	125

Table 11 *(continued)*

Symbol	Description	Unit	Pinion	Gear
σ_{FP}	Permissible tooth root stress	N/mm²	340	197
σ_H	Contact stress	N/mm²	612	579
$\sigma_{H\,lim}$	Limiting contact stress	N/mm²	1 009	328
σ_{H0}	Nominal contact stress	N/mm²	348	
σ_{HP}	Permissible contact stress	N/mm²	830	304
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-}B}$, $K_{H\alpha\text{-}B}$, $K_{F\alpha\text{-}B}$)	N/(mm·µm)	22,4	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	14,2	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	2,457	
N	Resonance ratio	—	0,19	
$K_{H\beta\text{-}C}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-}C}$, $K_{F\beta\text{-}C}$)	N/(mm·µm)	19,1	
f_{sh0}	Shaft deformation under specific load	µm	0,008	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	86,2	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	44,2	
y_α	Running-in allowance for a gear pair	µm	21,00	
y_β	Running-in allowance (equivalent misalignment)	µm	42,0	
f_{pb}	Transverse base pitch deviation	µm	88,3	
Eq for $F_{\beta x}$	—		52	
$f_{H\beta5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	19,0	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	5,6	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	78,8	

4.8 Example 6: Spur internal through-hardened gear pair

For example 6, input values and output values are given in Tables 12 and 13, respectively.

Table 12 — Example 6 input values

Type	Description	Unit	Symbol	Pinion	Wheel
Geometry	Number of teeth	—	z	15	−99
	Normal module	mm	m_n	12,00	
	Normal pressure angle	—	α	20,00	
	Helix angle	—	β	0,00	
	Hand of helix	—	—	—	—
	Face width (total)	mm	b	125,00	125,00
	Gap width	mm	—	0,00	0,00
	Edge chamfer	mm	—	0,00	0,00
	Contact face width (total)	mm	b_{eff}	125,00	
	Centre distance	mm	a	−500,00	
	Span measurement	mm	W_k	58,161	—
	Number of teeth spanned	—	k	2	—
	Dimension between balls	mm	M_{dK}	—	1 154,900
	Ball diameter	mm	D_M	—	21,60
	Nominal profile shift coefficient	—	x	0,323	0,000
	Generating profile shift coefficient (ref only)	—	x_E	(0,305)	(−0,018)
	Outside diameter	mm	d_a	211,75	−1 166,00
	Basic rack dedendum coefficient	—	h_{fP}/m_n	1,250	1,250
	Tip chamfer	mm		0,00	0,00
	Basic rack fillet root radius coefficient	—	ρ_{fP}/m_n	0,39	0,00
	As cut basic rack undercut	mm	pr	0,000	0,000
	Material allowance for finishing	mm	q	0,000	0,000
	Residual undercut (calculated - *pr*-*q*)	mm	s_{pr}	0,000	0,000
	Pinion cutter number of teeth	—	z_0	—	20
	Pinion cutter profile shift (ref)	—	x_0	—	0,00
	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	—	—	6	8
	Single pitch deviation	µm	f_{pt}	13,0	34,0
	Profile form deviation	µm	$f_{f\alpha}$	17,0	44,0
	Helix slope deviation	µm	$f_{H\beta}$	12,0	29,0
	Surface roughness – flank *Ra* (*Rz*)	µm	—	1,0 (6,0)	3,0 (18,0)
	Surface roughness – fillet *Ra* (*Rz*)	µm	—	3,0 (18,0)	3,0 (18,0)

Table 12 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Material	Material	—	—	V	V
	Material quality	—	—	MQ	MQ
	Case hardness	various	—	310 HV	260 HV
	Core hardness	various	—	—	—
	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	$\sigma_S/\sigma_{0,2}$	500,0	500,0
	Shot peen	—	—	No	No
	Limited pitting allowable	—	—	No	No
Application	Application factor	—	$K_{A\text{-}A}$	1,300	
	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	200,0	—
	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	1,000	
	Speed	rpm	n_1	360,0	
	Required life	hours	—	10 000	
	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

Table 13 — Example 6 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	180,00	−1 188,00
d_a	Tip diameter	mm	211,75	−1 166,00
d_b	Base circle diameter	mm	169,15	−1 116,36
d_f	Root diameter (based on x)	mm	157,75	−1 218,00
d_{Ff}	Root form diameter (based on x)	mm	169,77	−1 212,30
d_{Nf}	Start of active profile diameter	mm	169,90	−1 202,89
d_w	Working pitch diameter	mm	178,57	−1 178,57
F_t	Tangential tooth load	N	11 111	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,38	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,92	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,24	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	2,28	
$K_{v\text{-B}}$	Dynamic factor	—	1,12	
S_F	Tooth root breakage safety factor	—	6,89	5,37
S_H	Pitting safety factor	—	1,14	1,14
v	Pitch line velocity	m/s	3,39	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,31	1,18
Y_{NT}	Life factor for tooth root stress	—	0,92	0,95
Y_{RrelT}	Relative surface factor	—	0,96	0,96
Y_S	Stress correction factor	—	2,08	3,14
Y_{ST}	Stress correction factor for reference gears	—	2,00	
Y_X	Size factor	—	0,96	0,96
$Y_{\delta relT}$	Relative notch sensitivity factor	—	0,99	1,05
Z_B	Single pair tooth contact factor, pinion	—	1,01	
Z_β	Helix angle factor (pitting)	—	1,00	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N / mm^2}$	189,81	
Z_ε	Contact ratio factor	—	0,9	
Z_H	Zone factor	—	2,59	
Z_L	Lubrication factor	—	1,09	
Z_{NT}	Life factor for pitting stress	—	0,96	1,03
Z_R	Roughness factor	—	0,86	
Z_v	Velocity factor	—	0,95	
Z_W	Work hardening factor	—	1,00	1,00
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,57	
ε_β	Overlap ratio	—	0,00	
ε_γ	Total contact ratio	—	1,57	
σ_{F0}	Nominal tooth root stress	N/mm^2	20	27
σ_F	Tooth root stress	N/mm^2	78	105
$\sigma_{F\,lim}$	Limiting tooth root stress	N/mm^2	319	298

Table 13 *(continued)*

Symbol	Description	Unit	Pinion	Gear
σ_{FP}	Permissible tooth root stress	N/mm2	535	566
σ_H	Contact stress	N/mm2	583	579
$\sigma_{H\,lim}$	Limiting contact stress	N/mm2	780	714
σ_{H0}	Nominal contact stress	N/mm2	286	
σ_{HP}	Permissible contact stress	N/mm2	662	660
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-}B}$, $K_{H\alpha\text{-}B}$, $K_{F\alpha\text{-}B}$)	N/(mm·µm)	20,8	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	14,6	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	0,125	
N	Resonance ratio	—	0,04	
$K_{H\beta\text{-}C}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-}C}$, $K_{F\beta\text{-}C}$)	N/(mm·µm)	17,7	
f_{sh0}	Shaft deformation under specific load	µm	0,011	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	33,3	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	19,0	
y_α	Running-in allowance for a gear pair	µm	6,84	
y_β	Running-in allowance (equivalent misalignment)	µm	14,3	
f_{pb}	Transverse base pitch deviation	µm	31,9	
$Eq\ for\ F_{\beta x}$	—		52	
$f_{H\beta5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	10,0	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	1,4	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	31,4	

4.9 Example 7: Double helical through-hardened gear pair

For example 7, input values and output values are given in Tables 14 and 15, respectively.

Table 14 — Example 7 input values

Type	Description	Unit	Symbol	Pinion	Wheel
Geometry	Number of teeth	—	z	86	429
	Normal module	mm	m_n	1,693 3 (15 DP)	
	Normal pressure angle	—	α	20,00	
	helix angle	—	β	18,31	
	Hand of helix	—	—	Double helical	
	Face width (total)	mm	b	165,1 (82,55 × 2)	165,1 (82,55 × 2)
	Gap width	mm	—	50,80	50,80
	Edge chamfer	mm	—	0,00	0,00
	Contact face width (total)	mm	—	165,1 (82,55 × 2)	
	Centre distance	mm	a	460,38	
	Span measurement	mm	W_k	60,068	289,367
	Number of teeth spanned	—	k	12	56
	Dimension between balls	mm	M_{dK}	—	—
	Ball diameter	mm	D_M	—	—
	Nominal profile shift coefficient	—	x	0,3615	0,2863
	Generating profile shift coefficient (ref only)	—	x_E	(0,186 1)	(0,110 4)
	Outside diameter	mm	d_a	157,99	769,52
	Basic rack dedendum coefficient	—	h_{fP}/m_n	1,250	1,250
	Tip chamfer	mm		0,00	0,00
	Basic rack fillet root radius coefficient	—	ρ_{fP}/m_n	0,38	0,38
	As cut basic rack undercut	mm	pr	0,000	0,000
	Material allowance for finishing	mm	q	0,000	0,000
	Residual undercut (calculated - *pr-q*)	mm	s_{pr}	0,000	0,000
	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	—	—	Generating[a] (x_E)	Generating[a] (x_E)
	Tip relief	µm	C_a	13	

[a] Due to the reduction in tooth thickness resulting from the gear backlash as defined by the gear span size for this case, the application of generating profile coefficient, x_E, is required for the calculation of root form factor, Y_F, and root stress correction factor, Y_S. In accordance with ISO 6336-3:2006, 6.1, where the calculated tooth root thickness as determined by x_E results in a reduction in tooth thickness of ≥0,05 m_n of that determined using x, then x_E should be applied. The tooth root thickness assessment is taken at the root form diameter, d_{Nf}.

Table 14 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Quality	ISO accuracy grade	—	—	5	5
	Single pitch deviation	µm	f_{pt}	6,0	7,5
	Base pitch deviation	µm	f_{pb}	—	—
	Profile form deviation	µm	$f_{f\alpha}$	5,5	7,5
	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)
Material	Material	—	—	V	V
	Material quality	—	—	MQ	MQ
	Case hardness	—	—	350 HB	300 HB
	Core hardness	—	—	—	—
	Limiting contact stress	N/mm²	σ_{Hlim}	701	652
	Limiting tooth root stress	N/mm²	σ_{Flim}	251	239
	Young's modulus	N/mm²	E	206 000	206 000
	Poisson's ratio	—	ν	0,3	0,3
	Yield/proof stress	N/mm²	$\sigma_S/\sigma_{0,2}$	1 000,0	1 000,0
	Shot peen	—	—	No	No
	Limited pitting allowable	—	—	Yes	Yes
Application	Application factor	—	$K_{A\text{-}A}$	1,000	
	Reverse bending	—	—	No	No
	Favourable contact position	—	—	Yes	Yes
	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	355,600	—
	Bearing span offset	mm	s	0,00	—
	External shaft diameter	mm	d_{sh}	63,50	—
	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	mm²/s	ν_{40}	25	

[a] Due to the reduction in tooth thickness resulting from the gear backlash as defined by the gear span size for this case, the application of generating profile coefficient, x_E, is required for the calculation of root form factor, Y_F, and root stress correction factor, Y_S. In accordance with ISO 6336-3:2006, 6.1, where the calculated tooth root thickness as determined by x_E results in a reduction in tooth thickness of ≥0,05 m_n of that determined using x, then x_E should be applied. The tooth root thickness assessment is taken at the root form diameter, d_{Nf}.

Table 14 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Load	Torque	kNm	T_1	0,528	
	Speed	rpm	n_1	5 400,0	
	Required life	hours	—	30 000	
	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

[a] Due to the reduction in tooth thickness resulting from the gear backlash as defined by the gear span size for this case, the application of generating profile coefficient, x_E, is required for the calculation of root form factor, Y_F, and root stress correction factor, Y_S. In accordance with ISO 6336-3:2006, 6.1, where the calculated tooth root thickness as determined by x_E results in a reduction in tooth thickness of ≥0,05 m_n of that determined using x, then x_E should be applied. The tooth root thickness assessment is taken at the root form diameter, d_{Nf}.

Table 15 — Example 7 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	153,39	765,17
d_a	Tip diameter	mm	157,99	769,52
d_b	Base circle diameter	mm	143,23	714,47
d_f	Root diameter (based on x)	mm	150,38	761,92
d_{Ff}	Root form diameter (based on x)	mm	151,34	762,79
d_{Nf}	Start of active profile diameter	mm	151,40	763,15
d_w	Working pitch diameter	mm	153,76	767,00
F_t	Tangential tooth load	N	6 884	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,44	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,41	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,44	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	1,43	
$K_{v\text{-B}}$	Dynamic factor	—	1,81	
S_F	Tooth root breakage safety factor	—	2,01	1,85
S_H	Pitting safety factor	—	1,32	1,38
v	Pitch line velocity	m/s	43,37	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,17	1,21
Y_{NT}	Life factor for tooth root stress	—	0,85	0,88
Y_{RrelT}	Relative surface factor	—	0,96	0,96
Y_S	Stress correction factor	—	2,30	2,36
Y_{ST}	Stress correction factor for reference gears	—	2,00	
Y_X	Size factor	—	1,00	1,00
$Y_{\delta relT}$	Relative notch sensitivity factor	—	1,00	1,00
Z_B	Single pair tooth contact factor, pinion	—	1,00	
Z_β	Helix angle factor (pitting)	—	1,03	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N/mm^2}$	189,81	
Z_ε	Contact ratio factor	—	0,77	

Table 15 *(continued)*

Symbol	Description	Unit	Pinion	Gear
Z_H	Zone factor	—	2,37	
Z_L	Lubrication factor	—	0,85	
Z_{NT}	Life factor for pitting stress	—	0,85	0,95
Z_R	Roughness factor	—	0,94	
Z_v	Velocity factor	—	1,09	
Z_W	Work hardening factor	—	1,00	
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,68	
ε_β	Overlap ratio	—	4,87	
ε_γ	Total contact ratio	—	6,56	
σ_{F0}	Nominal tooth root stress	N/mm^2	56	60
σ_F	Tooth root stress	N/mm^2	205	220
$\sigma_{F\,lim}$	Limiting tooth root stress (input data)	N/mm^2	251	239
σ_{FP}	Permissible tooth root stress	N/mm^2	344	338
σ_H	Contact stress	N/mm^2	392	392
$\sigma_{H\,lim}$	Limiting contact stress (input data)	N/mm^2	701	652
σ_{H0}	Nominal contact stress	N/mm^2	203	
σ_{HP}	Permissible contact stress	N/mm^2	518	540
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-}B}$, $K_{H\alpha\text{-}B}$, $K_{F\alpha\text{-}B}$)	N/(mm·µm)	19,3	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	12,7	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	0,081	
N	Resonance ratio	—	3,16	
$K_{H\beta\text{-}C}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-}C}$, $K_{F\beta\text{-}C}$)	N/(mm·µm)	16,4	
f_{sh0}	Shaft deformation under specific load	µm	0,020	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	7,5	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	3,9	
y_α	Running-in allowance for a gear pair	µm	1,66	
y_β	Running-in allowance (equivalent misalignment)	µm	3,6	
f_{pb}	Transverse base pitch deviation	µm	7,0	
Eq for $F_{\beta x}$	—		53	
$f_{H\beta 5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	9,5	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	1,5	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	12,7	

4.10 Example 8: Single helical case carburized gear pair

NOTE Example 8 is the application of residual protuberance, *pr*.

For example 8, input values and output values are given in Tables 16 and 17, respectively.

Table 16 — Example 8 input values

Type	Description	Unit	Symbol	Pinion	Wheel
Geometry	Number of teeth	—	z	15	63
	Normal module	mm	m_n	4,50	
	Normal pressure angle	—	α	20,00	
	Helix angle	—	β	11,00	
	Hand of helix	—	—	Left	Right
	Face width (total)	mm	b	78,74	76,20
	Gap width	mm	—	0,00	0,00
	Edge chamfer	mm	—	0,00	0,00
	Contact face width (total)	mm	b_{eff}	76,20	
	Centre distance	mm	a	182,88	
	Span measurement	mm	W_k	35,706	118,358
	Number of teeth spanned	—	k	3	9
	Dimension between balls	mm	M_{dK}	—	—
	Ball diameter	mm	D_M	—	—
	Nominal profile shift coefficient	—	x	0,541 3	0,439 3
	Generating profile shift coefficient (ref only)	—	x_E	(0,486 7)	(0,407 0)
	Outside diameter	mm	d_a	82,19	301,55
	Basic rack dedendum coefficient	—	h_{fP}/m_n	1,516	1,516
	Tip chamfer	mm	—	0,00	0,00
	Basic rack fillet root radius coefficient	—	ρ_{fP}/m_n	0,40	0,40
	As cut basic rack undercut	mm	pr	0,267	0,267
	Material allowance for finishing	mm	q	0,220	0,220
	Residual undercut (calculated - *pr-q*)	mm	s_{pr}	0,047	0,047
	Cutting tool protuberance angle	—	—	10°	10°
	Pinion cutter number of teeth	—	z_0	—	—
	Pinion cutter profile shift (ref)	—	x_0	—	—
	Flank finishing process	—	—	Cut and ground	Cut and ground
	Root finishing process	—	—	As cut	As cut
	Profile shift coefficient used for calculations	—	—	Nominal (x)	Nominal (x)
	Tip relief	µm	C_a	13	
Quality	ISO accuracy grade	—	—	6	6
	Single pitch deviation	µm	f_{pt}	9,0	11,0
	Base pitch deviation	µm	f_{pb}		
	Profile form deviation	µm	$f_{f\alpha}$	10,0	13,0
	Helix slope deviation	µm	$f_{H\beta}$	10,0	11,0
	Surface roughness – flank *Ra* (*Rz*)	µm	—	0,38 (2,3)	0,38 (2,3)
	Surface roughness – fillet *Ra* (*Rz*)	µm	—	3,0 (18,0)	3,0 (18,0)

Table 16 *(continued)*

Type	Description	Unit	Symbol	Pinion	Wheel
Material	Material	—	—	Eh	Eh
	Material quality	—	—	MQ	MQ
	Case hardness	—	—	58 HRC	58 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	$\sigma_S/\sigma_{0,2}$	689,5	689,5
	Shot peen	—	—	No	No
	Limited pitting allowable	—	—	No	No
Application	Application factor	—	$K_{A\text{-}A}$	1,000	
	Reverse bending	—	—	No	No
	Favourable contact position	—	—	Yes	Yes
	Helix modification (ISO 6336-1:2006, Table 8)	—	—	Helix + Crowning (No. 5)	
	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)	—	—	b	
	Bearing span	mm	l	331,724	—
	Bearing span offset	mm	s	67,56	—
	External shaft diameter	mm	d_{sh}	63,50	—
	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}	220	
Load	Torque	kNm	T_1	1,494	
	Speed	rpm	n_1	1 430,0	
	Required life	hours	—	10 000	
	Life factor for contact stress, Z_{NT}, at 10^{10} cycles	—	—	1,00	1,00
	Life factor for tooth root stress, Y_{NT}, at 10^{10} cycles	—	—	1,00	1,00

Table 17 — Example 8 output values

Symbol	Description	Unit	Pinion	Gear
d	Reference diameter	mm	68,76	288,81
d_a	Tip diameter	mm	82,19	301,55
d_b	Base circle diameter	mm	64,47	270,79

Table 17 *(continued)*

Symbol	Description	Unit	Pinion	Gear
d_f	Root diameter (based on x_E — pre-hobbing)	mm	60,79	280,12
d_{Ff}	Root form diameter (based on x_E — grinding)	mm	65,87	284,04
d_{Nf}	Start of active profile diameter	mm	65,88	287,05
d_w	Working pitch diameter	mm	70,34	295,42
F_t	Tangential tooth load	N	43 451	
$K_{F\alpha\text{-B}}$	Transverse load factor (root stress)	—	1,05	
$K_{F\beta\text{-C}}$	Face load factor (root stress)	—	1,05	
$K_{H\alpha\text{-B}}$	Transverse load factor (contact stress)	—	1,05	
$K_{H\beta\text{-C}}$	Face load factor (contact stress)	—	1,06	
$K_{v\text{-B}}$	Dynamic factor	—	1,02	
S_F	Tooth root breakage safety factor	—	2,69	2,43
S_H	Pitting safety factor	—	1,23	1,23
v	Pitch line velocity	m/s	5,15	
Y_B	Rim thickness factor	—	1,00	1,00
Y_{DT}	Deep tooth factor	—	1,00	
Y_F	Tooth form factor	—	1,39	1,49
Y_{NT}	Life factor for tooth root stress	—	1,00	1,00
Y_{RrelT}	Relative surface factor	—	0,96	0,96
Y_S	Stress correction factor	—	2,06	2,07
Y_{ST}	Stress correction factor for reference gears	—	2,00	
Y_X	Size factor	—	1,00	1,00
$Y_{\delta relT}$	Relative notch sensitivity factor	—	1,00	1,00
Z_B	Single pair tooth contact factor, pinion	—	1,00	
Z_β	Helix angle factor (pitting)	—	1,01	
Z_D	Single pair tooth contact factor, wheel	—	1,00	
Z_E	Elasticity factor	$\sqrt{N/mm^2}$	189,81	
Z_ε	Contact ratio factor	—	0,85	
Z_H	Zone factor	—	2,27	
Z_L	Lubrication factor	—	1,02	
Z_{NT}	Life factor for pitting stress	—	1,00	1,00
Z_R	Roughness factor	—	1,03	
Z_v	Velocity factor	—	0,98	
Z_W	Work hardening factor	—	1,00	
Z_X	Size factor	—	1,00	
ε_α	Transverse contact ratio	—	1,39	
ε_β	Overlap ratio	—	1,03	
ε_γ	Total contact ratio	—	2,41	
σ_{F0}	Nominal tooth root stress	N/mm^2	318	353
σ_F	Tooth root stress	N/mm^2	357	397
$\sigma_{F\,lim}$	Limiting tooth root stress	N/mm^2	500	500
σ_{FP}	Permissible tooth root stress	N/mm^2	963	965
σ_H	Contact stress	N/mm^2	1 257	1 257

Table 17 *(continued)*

Symbol	Description	Unit	Pinion	Gear
$\sigma_{H\,lim}$	Limiting contact stress	N/mm2	1 500	1 500
σ_{H0}	Nominal contact stress	N/mm2	1 181	
σ_{HP}	Permissible contact stress	N/mm2	1 542	1 542
Intermediate calculation values				
$K_{v\text{-}B}$ intermediate calculation values				
$c_{\gamma\alpha}$	Mean value of mesh stiffness per unit face width (used for $K_{v\text{-}B}$, $K_{H\alpha\text{-}B}$, $K_{F\alpha\text{-}B}$)	N/(mm·µm)	17,5	
c'	Maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)	13,5	
m_{red}	Reduced gear pair mass per unit face width referenced to the line of action	kg/mm	0,018	
N	Resonance ratio	—	0,07	
$K_{H\beta\text{-}C}$ intermediate calculation values				
$c_{\gamma\beta}$	Mean value of mesh stiffness per unit face width (used for $K_{H\beta\text{-}C}$, $K_{F\beta\text{-}C}$)	N/(mm·µm)	14,8	
f_{sh0}	Shaft deformation under specific load	µm	0,136	
$F_{\beta x}$	Initial equivalent misalignment (before running in)	µm	5,5	
$F_{\beta y}$	Initial equivalent misalignment (after running in)	µm	4,7	
y_{α}	Running-in allowance for a gear pair	µm	0,77	
y_{β}	Running-in allowance (equivalent misalignment)	µm	0,8	
f_{pb}	Transverse base pitch deviation	µm	10,3	
$Eq\ for\ F_{\beta x}$	—		55	
$f_{H\beta 5}$	Tolerance on helix slope deviation for ISO accuracy grade 5	µm	8,0	
f_{sh}	Component of equivalent misalignment due to deformations of pinion and wheel shafts	µm	79,0	
f_{ma}	Mesh misalignment due to manufacturing deviations	µm	14,9	

Annex A
(informative)

Example 1 detailed calculation

A.1 General

This annex contains the detailed calculation example 1. The formulae are numbered according to the respective referenced document.

A.2 Defined data

The defined data are shown in Tables A.1, A.2 and A.3.

Table A.1 — Gear geometry

Description	Pinion	Wheel
Number of teeth	$z_1 = 17$	$z_2 = 103$
Normal module	$m_n = 8$	
Normal pressure angle	$\alpha_n = 20{,}00°$	
Helix angle	$\beta = 15{,}8°$	
Hand of helix	Left	Right
Face width	$b_1 = 100$ mm	$b_2 = 100$ mm
Contact face width	$b = 100$ mm	
Centre distance	$a_w = 500$ mm	
Nominal addendum correction factor	$x_1 = 0{,}145$	$x_2 = 0$
Span measurement	$W_{k1} = 38{,}196$ mm	$W_{k2} = 307{,}943$ mm
Number of teeth spanned	$k_1 = 2$	$k_2 = 13$
Outside diameter	$d_{a1} = 159{,}66$ mm	$d_{a2} = 872{,}35$ mm
Basic rack dedendum	$h_{fP1} = 1{,}4\ m_n$ mm	$h_{fP2} = 1{,}4\ m_n = 11{,}2$ mm
Basic rack fillet root radius	$\rho_{fP1} = 0{,}39\ m_n$ mm	$\rho_{fP2} = 0{,}39\ m_n = 3{,}12$ mm
Residual undercut	$s_{pr1} = 0{,}00$ mm	$s_{pr2} = 0{,}00$ mm
Material allowance for finishing	$q_1 = 0{,}00$ mm	$q_2 = 0{,}00$ mm
Tip relief	$C_a = 70$ µm	

Table A.2 — Gear quality

Description	Pinion	Wheel
ISO accuracy grade	Q = 5	Q = 5
Transverse pitch deviation	$f_{pt1} = 8{,}0$ µm	$f_{pt2} = 9{,}5$ µm
Profile form deviation	$f_{\alpha1} = 10{,}0$ µm	$f_{\alpha2} = 12{,}0$ µm
Helix slope deviation	$H_{\beta1} = 8{,}5$ µm	$H_{\beta2} = 9{,}5$ µm
Surface roughness (*Ra*)	$Ra_{H1} = 1{,}0$ µm	$Ra_{H2} = 1{,}0$ µm
Fillet roughness (*Ra*)	$Ra_{F1} = 3{,}0$ µm	$Ra_{F2} = 3{,}0$ µm

Table A.3 — Material data

Description	Pinion	Wheel
Material type	Eh	Eh
Material quality	MQ	MQ
Case hardness (HRC)	60	60
Core hardness (HRC)	30	30
Young's modulus	E_1 = 206 000 N/mm^2	E_2 = 206 000 N/mm^2
Poisson's ratio	ν_1 = 0,3	$\nu 2$ = 0,3
Yield/proof stress	σ_{S1} = 500	σ_{S2} = 500
Shot peen	No	No
Limited pitting allowable	No	No

A.3 ISO 6336-5:2016 — Allowable stress values for contact and bending

5.5 Allowable contact stress number, $\sigma_{\text{H lim}}$

For material Eh with MQ quality (see ISO 6336-5:2016, Table 1),

$$\sigma_{\text{H lim}} = 1\,500\ \text{N/mm}^2$$

Minimum required safety value for contact, $S_{\text{H min}}$ = 1,00

Allowable stress numbers (bending), $\sigma_{\text{F lim}}$

For material Eh, material quality MQ with core hardness ≥ = 30 HRC (see ISO 6336-5:2016, Figure 10),

$$\sigma_{\text{F lim}} = 500\ \text{N/mm}^2$$

Minimum safety value for bending, $S_{\text{F min}}$ = 1,00

A.4 Application data

See Table A.4.

Table A.4 — Application data

Description	Pinion	Wheel
Application factor	K_A = 1,00	
Reverse bending	No	No
Favourable contact position	No	No
Helix modification	No	No
Number of mesh contacts	N_{M1} = 1	N_{M2} = 1
Gear blank type	Solid	Solid
Bearing span offset	s_1 = 0,00 mm	
Equivalent misalignment	f_{sh} = 0 µm	
Mesh misalignment	f_{ma} = 0 µm	
Lubrication viscosity	ν_{40} = 320 cSt	

A.5 Load data

See Table A.5.

Table A.5 — Load data

Description	Pinion	Wheel
Pinion torque	T_1 = 9 000 Nm	
Pinion speed	n_1 = 360 rpm	
Required life	L_h = 50 000 h	

A.6 Supplementary calculations

Gear ratio

$$u=\frac{z_2}{z_1}=6{,}058\,82$$

Transverse module

$$m_t=\frac{m_n}{\cos(\beta)}=8{,}314\,12\text{ mm}$$

Reference diameter

$$d_1=z_1\,m_t=141{,}340\,11\text{ mm}$$

$$d_2=z_2\,m_t=856{,}354\,80\text{ mm}$$

Involute normal pressure angle

$$\text{inv}\alpha_t=\tan(\alpha_n)-\alpha_n=0{,}014\,90\text{ rad}$$

Transverse pressure angle

$$\alpha_t=a\tan\left[\frac{\tan(\alpha_n)}{\cos(\beta)}\right]=20{,}719\,71°$$

$$\text{inv}\alpha_t=\tan(\alpha_{wt})-\alpha_{wt}=0{,}016\,63\text{ rad}$$

Transverse working pressure angle

$$\alpha_{wt}=a\cos\left\{|z_1+z_2|\left[\frac{m_n\cos(\alpha_t)}{2a_w\cos(\beta)}\right]\right\}=21{,}066\,10°$$

$$\text{inv}\alpha_t=\tan(\alpha_t)-\alpha_t=0{,}016\,63\text{ rad}$$

Generating profile shift coefficient

$$x_{E1}=\frac{W_{k1}-\left\{m_n\cos(\alpha_n)\left[\pi(k_1-0{,}5)+z_1\text{inv}\alpha_t\right]\right\}}{2\,m_n\sin(\alpha_n)}=0{,}117\,79$$

$$x_{E1}=\frac{W_{k2}-\left\{m_n\cos(\alpha_n)\left[\pi(k_2-0{,}5)+z_2\text{inv}\alpha_t\right]\right\}}{2\,m_n\sin(\alpha_n)}=-0{,}027\,48$$

Root diameter

(calculated using nominal profile shift coefficient, x)

$$d_{f1}=d_1-2\left[h_{fP1}-(x_1m_n)\right]=121{,}260\,11\text{ mm}$$

$$d_{f2}=d_2-2\left[h_{fP2}-(x_2m_n)\right]=833{,}954\,80\text{ mm}$$

Base diameter

$$d_{b1}=d_1\cos(\alpha_t)=132{,}198\,57\text{ mm}$$

$$d_{b2}=d_2\cos(\alpha_t)=800{,}967\,80\text{ mm}$$

Base helix angle	$\beta_b = a\tan\left[\tan(\beta)\cos(\alpha_t)\right] = 14{,}824\,53°$
Working pitch diameter	$d_{w1} = \frac{d_{b1}}{\cos(\alpha_{wt})} = 141{,}666\,67\ \text{mm}$ $d_{w2} = \frac{d_{b2}}{\cos(\alpha_{wt})} = 858{,}333\,33$
Normal pitch	$p_n = \pi\, m_n\ \text{mm}$
Transverse pitch	$p_t = \pi\, m_t = 26{,}119\,59\ \text{mm}$
Transverse base pitch	$p_{bt} = p_t \cos(\alpha_t) = 24{,}430\,24\ \text{mm}$
Transverse base pitch on the path of contact	$p_{et} = p_{bt} = 24{,}430\,24\ \text{mm}$
Length of line of contact	$g_\alpha = \frac{1}{2}\left[\sqrt{d_{a1}{}^2 - d_{b1}{}^2} + \frac{z_2}{\lvert z_2\rvert}\left(\sqrt{d_{a2}{}^2 - d_{b2}{}^2} - 2a_w \sin\right)\right] = 37{,}844\,64\ \text{mm}$
SAP diameter	$d_{Nf1} = 2\sqrt{\left[\sqrt{\left(\frac{d_{a1}}{2}\right)^2 - \left(\frac{d_{b1}}{2}\right)^2} - g_\alpha\right]^2 + \left(\frac{d_{b1}}{2}\right)^2} = 132{,}921\ \text{mm}$ $d_{Nf2} = 2\sqrt{\left[\sqrt{\left(\frac{d_{a2}}{2}\right)^2 - \left(\frac{d_{b2}}{2}\right)^2} - g_\alpha\right]^2 + \left(\frac{d_{b2}}{2}\right)^2} = 854{,}225\ \text{mm}$
Transverse contact ratio	$\varepsilon_\alpha = \frac{g_\alpha}{p_{et}} = 1{,}549\,09$
Overlap ratio	$\varepsilon_\beta = \frac{b\sin(\beta)}{m_n\,\pi} = 1{,}083\,37$
Total contact ratio	$\varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta = 2{,}632\,46$
Transverse base pitch deviation	$f_{pb1} = f_{pt1}\cos(\alpha_t) = 7{,}482\,58\ \mu\text{m}$ $f_{pb2} = f_{pt2}\cos(\alpha_t) = 8{,}885\,56\ \mu\text{m}$
Pitch line velocity (see ISO 6336-1:2006, 4.2.1)	$v = \frac{d_1\,\pi\, n_1}{60\cdot 10^3} = 2{,}664\,\frac{\text{m}}{\text{s}}$

A.7 ISO 6336-2:2006 — Contact ratio factor

8.1 Contact ratio factor, Z_ε

$$Z_\varepsilon = \sqrt{\frac{1}{\varepsilon_\alpha}} = 0{,}803 \tag{26}$$

A.8 ISO 6336-1:2006 — Basic principles, introduction and general influence factors

A.8.1 Determination of dynamic factor, k_v

4.2.1 Nominal tangential load, F_t

$$F_t = \frac{2\,000\,T_1}{d_1} = 127\,352\,\text{N} \quad (1)$$

9.3 Determination of tooth stiffness parameters, c' and c_γ

Virtual number of teeth, z_n

$$z_{n1} = \frac{z_1}{\cos(\beta_b)^2 \cos(\beta)} = 18{,}905$$

$$z_{n2} = \frac{z_2}{\cos(\beta_b)^2 \cos(\beta)} = 114{,}543$$

9.3.1.1 Theoretical single stiffness, c'_{th}

Coefficients:

$C_1 = 0{,}047\,23$

$C_2 = 0{,}155\,51$

$C_3 = 0{,}257\,91$

$C_4 = -0{,}006\,35$

$C_5 = -0{,}116\,54$

$C_6 = -0{,}001\,93$

$C_7 = -0{,}241\,88$

$C_8 = 0{,}005\,29$

$C_9 = 0{,}001\,82$

Minimum value for the flexibility of gear pair, q'

$$q' = C_1 + \frac{C_2}{z_{n1}} + \frac{C_3}{z_{n2}} + C_4 x_1 + \frac{C_5 x_1}{z_{n1}} + C_6 x_2 + \frac{C_7 x_2}{z_{n2}} + C_8 {x_1}^2 + C_9 {x_2}^2 = 0{,}056\,00\,(\text{mm}\cdot\mu\text{m})/\text{N}$$

$$c'_{th} = \frac{1}{q'} = 17{,}855\,84\ \text{N}/(\text{mm}\cdot\mu\text{m}) \tag{81}$$

9.3.1.2 Correction factor, C_M

$$C_M = 0{,}8 \tag{83}$$

9.3.1.3 Gear blank factor, C_R

$$C_R = 1{,}0\ (\text{for solid gears}) \tag{84}$$

9.3.1.4 Basic rack factor, C_B

Normal pressure angle of basic rack, $\alpha_{Pn} = \alpha_n$

Basic rack dedendum for pinion and gear are the same, therefore,

$$C_{B1} = \left[1{,}0 + 0{,}5\left(1{,}2 - \frac{h_{fP1}}{m_n}\right)\right]\left[1{,}0 - 0{,}02(20° - \alpha_{Pn})\right] = 0{,}900\,00 \tag{86}$$

$$C_{B2} = \left[1{,}0 + 0{,}5\left(1{,}2 - \frac{h_{fP2}}{m_n}\right)\right]\left[1{,}0 - 0{,}02(20° - \alpha_{Pn})\right] = 0{,}900\,00$$

$$C_B = 0{,}5(C_{B1} + C_{B2}) \tag{87}$$

9.3.1 Single stiffness, c'

$$c' = c'_{th}\ C_M\ C_R\ C_B \cos(\beta) = 12{,}370\,47\ \text{N}/(\text{mm}\cdot\mu\text{m}) \tag{80}$$

9.3.2.1 Mesh stiffness, $c_{\gamma\alpha}$

$$c_{\gamma\alpha} = c'^{(0{,}75\varepsilon_\alpha + 0{,}25)} = 17{,}464\,85\ \text{N}/(\text{mm}\cdot\mu\text{m}) \tag{91}$$

9.3.2.2 Mesh stiffness, $c_{\gamma\beta}$

$$c_{\gamma\beta} = 0{,}85\, c_{\gamma\alpha} = 14{,}845\,12\ \text{N}/(\text{mm}\cdot\mu\text{m}) \tag{92}$$

6.4.8 Calculation of reduced mass of gear pair with external teeth, m_{red}

Mean tooth diameter, d_m

$$d_{m1} = \frac{d_{a1} + d_{f1}}{2} = 140{,}460\,06 \qquad d_{m2} = \frac{d_{a2} + d_{f2}}{2} = 853{,}152\,40 \tag{31}$$

Assume density ρ_1 = 0,000 007 83 kg/mm³ ρ_2 = 0,000 007 83 kg/mm³

$$m_{red} = \frac{\pi}{8}\left(\frac{d_{m1}}{d_{b1}}\right)^2 \frac{{d_{m1}}^2}{\dfrac{1}{1{,}0\,\rho_1} + \dfrac{1}{1{,}0\,\rho_2 u^2}} = 0{,}066\,67\ \text{kg}/\text{mm} \tag{30}$$

NOTE Quantity $(1 - q_1{}^4) = (1 - q_2{}^4) = 1$ for solid pinion and wheel. (33)

6.4.2 Determination of resonance running speed, n_{E1}

$$n_{E1} = \frac{30000}{\pi z_1}\sqrt{\frac{c_{\gamma\alpha}}{m_{red}}} = 9\,091{,}83\ \text{min}^{-1} \quad (6)$$

Resonance ratio, N

$$N = \frac{n_1}{n_{E1}} = 0{,}0396 \quad (9)$$

Lower limit of resonance ratio, N_S

$$\frac{F_t K_A}{b} > 100,\ \text{therefore},\ N_S = 0{,}85 \quad (12)$$

6.4.3 Dynamic factor in subcritical range, $(N \le N_S)$

$\varepsilon_\gamma > 2$ (see Table 5), therefore,

$$C_{v1} = 0{,}32$$

$$C_{v2} = \frac{0{,}57}{\varepsilon_\gamma} = 0{,}244$$

$$C_{v3} = \frac{0{,}096}{\varepsilon_\gamma - 1{,}56} 0{,}09$$

$\varepsilon_\gamma > 2{,}5$

$$C_{v4} = \frac{0{,}57 - 0{,}05\,\varepsilon_\gamma}{\varepsilon_\gamma - 1{,}44} = 0{,}368$$

$$C_{v5} = 0{,}47 = 0{,}47$$

$$C_{v6} = \frac{0{,}12}{\varepsilon_\gamma - 1{,}74} = 0{,}134$$

$$C_{v7} = 1$$

$$C_{ay} = \frac{1}{18}\left(\frac{\sigma_{H\,lim}}{97} - 18{,}45\right)^2 + 1{,}5 = 1{,}995\ \mu\text{m}$$

Base pitch deviation, $f_{pb} = \max\left(f_{pb1}, f_{pb2}\right) = 8{,}88556\ \mu\text{m}$ (see note in ISO 6336-1:2006, 8.3.1)

Profile form deviation, $f_{f\alpha} = \max\left(f_{f\alpha1}, f_{f\alpha2}\right) = 12\ \mu\text{m}$

Running in allowance (see ISO 6336-1:2006, 8.3.5)

As materials are the same and for Eh material, then,

$$y_\alpha = 0{,}075 f_{pb} = 0{,}666\ \mu\text{m} \quad (77)$$

Check that it is not greater than allowable limit for material Eh of 3 µm.

Estimated running in allowance (pitch deviation) (see note in ISO 6336-1:2006, 6.4.3)

$$y_p = y_\alpha = 0{,}666\ \mu\text{m}$$

Estimated running an allowance (flank deviation) (see note in ISO 6336-1:2006, 6.4.3)

$$y_f = 0{,}075\, f_{f\alpha} = 0{,}9$$

Check that it is not greater than allowable limit for material Eh of 3 µm.

$$f_{\text{pbeff}} = f_{\text{pb}} - y_{\text{p}} = 8{,}219\,15 \qquad (18)$$

$$f_{\text{f}\alpha\text{eff}} = f_{\text{f}\alpha} - y_{\text{f}} = 11{,}100\,00 \qquad (19)$$

$$B_{\text{p}} = \frac{c' f_{\text{pbeff}}}{K_{\text{A}}\left(\frac{F_{\text{t}}}{b}\right)} = 0{,}079\,84 \qquad (15)$$

$$B_{\text{f}} = \frac{c' f_{\text{f}\alpha\text{eff}}}{K_{\text{A}}\left(\frac{F_{\text{t}}}{b}\right)} = 0{,}107\,82 \qquad (16)$$

As lowest accuracy grade ≤ ISO accuracy grade 5, then,

$$B_{\text{k}} = \left|1 - \frac{c' C_{\text{a}}}{K_{\text{A}}\left(\frac{F_{\text{t}}}{b}\right)}\right| = 0{,}32 \qquad (17)$$

$$k = (C_{\text{v1}} B_{\text{p}}) + (C_{\text{v2}} B_{\text{f}}) + (C_{\text{v3}} B_{\text{k}}) = 0{,}080\,55 \qquad (14)$$

As $N \leq N_{\text{S}}$, (see ISO 6336-1:2006, 6.4.3), then,

$$K_{\text{v}} = NK + 1 = 1{,}003 \qquad (13)$$

A.8.2 Determination of face load factors, $K_{\text{H}\beta}$ and $K_{\text{F}\beta}$

Mean transverse tangential load (see 3.2)

$$F_{\text{m}} = F_{\text{t}} K_{\text{A}} K_{\text{v}} = 127\,759\ \text{N}$$

7.5.2.4.1 Approximate calculation of equivalent misalignment, f_{sh}

Pinion offset s_1 = 0, therefore,

$$f_{\text{sh}} = \frac{F_{\text{m}}}{b} 0{,}023\left[(1 + 0 - 0{,}3) + 0{,}3\right]\left(\frac{b}{d_1}\right)^2 = 14{,}709\,13\ \mu\text{m} \qquad (57)$$

7.5.3.3 Mesh misalignment, f_{ma}

$$f_{\text{ma}} = \sqrt{f_{\text{H}\beta 1}{}^2 + f_{\text{H}\beta 2}{}^2} = 12{,}747\,55\ \mu\text{m} \qquad (64)$$

7.5.2.3 Initial equivalent misalignment, $F_{\beta x}$

As no helix modification is applied,

$B_1 = 1$ $B_2 = 1$ (see Table 9)

$$F_{\beta x} = 1{,}33 B_1\ f_{sh} + B_2\ f_{ma} = 32{,}310\,69\ \mu m \tag{52}$$

7.5.2.1 Running-in allowance, y_β and X_β

As materials are the same and for Eh material,

$$y_\beta = 0{,}15\, F_{\beta x} = 4{,}847\ \mu m \tag{48}$$

Check that it is not greater than allowable limit for material Eh of 6 µm.

$$x_{\beta 2} = 0{,}85 \tag{49}$$

7.5.1 Effective equivalent misalignment, $F_{\beta y}$

$$F_{\beta y} = F_{\beta x} - y_\beta = 27{,}464\,09\ \mu m \tag{43}$$

7.5 Face load factor, $K_{H\beta\text{-C}}$

$$\frac{F_{\beta y} c_{\gamma\beta}}{2\dfrac{F_m}{b}} < 1$$

therefore,

$$K_{H\beta} = \left(1 + \frac{F_{\beta y} c_{\gamma\beta}}{2\dfrac{F_m}{b}}\right) = 1{,}16 \tag{41}$$

7.6 Face load factor, $K_{F\beta}$

$$h_1 = \frac{d_{a1} - d_{f1}}{2} = 19{,}199\,94\ mm \qquad \frac{b_1}{h_1} = 5{,}208\ 35$$

$$h_2 = \frac{d_{a2} - d_{f2}}{2} = 19{,}197\,6\ mm \qquad \frac{b_2}{h_2} = 5{,}208\ 98$$

$$N_F = \frac{1}{1 + \dfrac{h_1}{b_1} + \left(\dfrac{h_1}{b_1}\right)^2} = 0{,}813\,76 \tag{70}$$

$$K_{F\beta} = K_{H\beta}^{\ N_F} = 1{,}128\,03 \tag{69}$$

