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Calculation of micropitting load capacity of cylindrical spur and helical gears

Part 2: Examples of calculation for micropitting

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National foreword

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30 September 2015	Implementation of ISO corrected text 15 January 2015: errors in symbols and equations have been corrected

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TECHNICAL REPORT

ISO/TR 15144-2

First edition
2014-10-01

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2015-01-15

Calculation of micropitting load capacity of cylindrical spur and helical gears —

Part 2: Examples of calculation for micropitting

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

Partie 2: Exemples de calcul pour micropiqûres

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

This corrected version of ISO/TR 15144-2:2014 incorporates the following corrections: errors in symbols and equations have been corrected.

ISO/TR 15144 consists of the following parts, under the general title *Calculation of micropitting load capacity of cylindrical spur and helical gears*:

— *Part 1: Introduction and basic principles*

— *Part 2: Examples of calculation for micropitting*

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Introduction

This part of ISO/TR 15144 provides worked examples for the application of the calculation procedures defined in ISO/TR 15144-1. The example calculations cover the application to spur and helical cyclindrical involute gears for both high-speed and low-speed operating conditions, determining the micropitting safety factor for each gear pair. The calculation procedures used are consistent with those presented in ISO/TR 15144-1. No additional calculations are presented here that are outside of the technical report.

Four worked examples are presented with the necessary input data for each gear set provided at the beginning of the calculation. The worked examples are based on real gear pairs where either laboratory or operational field performance data has been established, with the examples covering several applications. When available, pictures and measurements are provided of the micropitting wear, experienced on the gear sets when run under the conditions used in the worked examples. Calculation details are presented in full for several of the initial calculations after which only summarized results data are included. For better applicability, the numbering of the formulae follows ISO/TR 15144-1. Several of the worked examples are presented with the calculation procedures performed in accordance with the application of both methods A and B.

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Calculation of micropitting load capacity of cylindrical spur and helical gears —

Part 2: Examples of calculation for micropitting

1 Scope

The example calculations presented here are provided for guidance on the application of the technical report ISO/TR 15144-1 only. Any of the values or the data presented should not be used as material or lubricant allowables or as recommendations for micro-geometry in real applications when applying this procedure. The necessary parameters and allowable film thickness values, λ_{GFP}, should be determined for a given application in accordance with the procedures defined in ISO/TR 15144-1.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 6336-1:2006, *Calculation of load capacity of spur and helical gears — Part 1: Basic principles, introduction and general influence factors*

ISO 6336-2:2006, *Calculation of load capacity of spur and helical gears — Part 2: Calculation of surface durability (pitting)*

ISO 21771:2007, *Gears — Cylindrical involute gears and gear pairs — Concepts and geometry*

ISO/TR 15144-1:2014, *Calculation of micropitting load capacity of cylindrical spur and helical gears — Part 1: Introduction and basic principles*

3 Terms, definitions, symbols, and units

3.1 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 1122-1, ISO 6336-1, and ISO 6336-2 apply.

3.2 Symbols and units

The symbols used in this technical report are given in Table 1. 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.

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Table 1 — Symbols and units

Symbol	Description	Unit
a	centre distance	mm
B_{M1}	thermal contact coefficient of pinion	N/(m·s^{0,5}·K)
B_{M2}	thermal contact coefficient of wheel	N/(m·s^{0,5}·K)
b	face width	mm
C_{a1}	tip relief of pinion	µm
C_{a2}	tip relief of wheel	µm
c_{M1}	specific heat per unit mass of pinion	J/(kg·K)
c_{M2}	specific heat per unit mass of wheel	J/(kg·K)
c'	maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	N/(mm·µm)
$c_{\gamma\alpha}$	mean value of mesh stiffness per unit face width	N/(mm·µm)
d_{a1}	tip diameter of pinion	mm
d_{a2}	tip diameter of wheel	mm
d_{b1}	base diameter of pinion	mm
d_{b2}	base diameter of wheel	mm
d_{w1}	pitch diameter of pinion	mm
d_{w2}	pitch diameter of wheel	mm
d_{Y1}	Y-circle diameter of pinion	mm
d_{Y2}	Y-circle diameter of wheel	mm
E_r	reduced modulus of elasticity	N/mm^2
E_1	modulus of elasticity of pinion	N/mm^2
E_2	modulus of elasticity of wheel	N/mm^2
F_{bt}	nominal transverse load in plane of action (base tangent plane)	N
F_t	(nominal) transverse tangential load at reference cylinder per mesh	N
G_M	material parameter	-
g_Y	parameter on the path of contact (distance of point Y from point A)	mm
g_α	length of path of contact	mm
H_v	load losses factor	-
h_Y	local lubricant film thickness	µm
K_A	application factor	-
$K_{H\alpha}$	transverse load factor	-
$K_{H\beta}$	face load factor	-
K_v	dynamic factor	-
n_1	rotation speed of pinion	min^{-1}
P	transmitted power	kW
p_{et}	transverse base pitch on the path of contact	Mm
$p_{dyn,Y}$	local Hertzian contact stress including the load factors K	N/mm^2
$p_{H,Y}$	local nominal Hertzian contact stress	N/mm^2
Ra	effective arithmetic mean roughness value	µm
Ra_1	arithmetic mean roughness value of pinion	µm
Ra_2	arithmetic mean roughness value of wheel	µm
$S_{GF,Y}$	local sliding parameter	-

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Table 1 *(continued)*

Symbol	Description	Unit
S_λ	safety factor against micropitting	-
$S_{\lambda,\min}$	minimum required safety factor against micropitting	-
T_1	nominal torque at the pinion	Nm
U_Y	local velocity parameter	-
u	gear ratio	-
$v_{g,Y}$	local sliding velocity	m/s
$v_{r1,Y}$	local tangential velocity on pinion	m/s
$v_{r2,Y}$	local tangential velocity on wheel	m/s
$v_{\Sigma,C}$	sum of tangential velocities at pitch point	m/s
$v_{\Sigma,Y}$	sum of tangential velocities at point Y	m/s
W_W	material factor	-
W_Y	local load parameter	-
$X_{but,Y}$	local buttressing factor	-
X_{Ca}	tip relief factor	-
X_L	lubricant factor	-
X_R	roughness factor	-
X_S	lubrication factor	-
X_Y	local load sharing factor	-
Z_E	elasticity factor	$(N/mm^2)^{0,5}$
z_1	number of teeth of pinion	-
z_2	number of teeth of wheel	-
α_t	transverse pressure angle	°
α_{wt}	pressure angle at the pitch cylinder	°
$\alpha_{\theta B,Y}$	pressure-viscosity coefficient at local contact temperature	m^2/N
$\alpha_{\theta M}$	pressure-viscosity coefficient at bulk temperature	m^2/N
α_{38}	pressure-viscosity coefficient at 38 °C	m^2/N
β_b	base helix angle	°
ε_{max}	maximum addendum contact ratio	-
ε_α	transverse contact ratio	-
$\varepsilon_{\alpha n}$	virtual transverse contact ratio	-
ε_β	overlap ratio	-
ε_γ	total contact ratio	-
ε_1	addendum contact ratio of the pinion	-
ε_2	addendum contact ratio of the wheel	-
$\eta_{\theta B,Y}$	dynamic viscosity at local contact temperature	$N{\cdot}s/m^2$
$\eta_{\theta M}$	dynamic viscosity at bulk temperature	$N{\cdot}s/m^2$
$\eta_{\theta oil}$	dynamic viscosity at oil inlet/sump temperature	$N{\cdot}s/m^2$
η_{38}	dynamic viscosity at 38 °C	$N{\cdot}s/m^2$
$\theta_{B,Y}$	local contact temperature	°C
$\theta_{fl,Y}$	local flash temperature	°C
θ_M	bulk temperature	°C

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Table 1 *(continued)*

Symbol	Description	Unit
θ_{oil}	oil inlet/sump temperature	°C
$\lambda_{GF,min}$	minimum specific lubricant film thickness in the contact area	-
$\lambda_{GF,Y}$	local specific lubricant film thickness	-
λ_{GFP}	permissible specific lubricant film thickness	-
λ_{GFT}	limiting specific lubricant film thickness of the test gears	-
λ_{M1}	specific heat conductivity of pinion	W/(m·K)
λ_{M2}	specific heat conductivity of wheel	W/(m·K)
μ_m	mean coefficient of friction	-
$\nu_{\theta B,Y}$	kinematic viscosity at local contact temperature	mm^2/s
$\nu_{\theta M}$	kinematic viscosity at bulk temperature	mm^2/s
ν_1	Poisson's ratio of pinion	-
ν_2	Poisson's ratio of wheel	-
ν_{100}	kinematic viscosity at 100 °C	mm^2/s
ν_{40}	kinematic viscosity at 40 °C	mm^2/s
ρ_{M1}	density of pinion	kg/m^3
ρ_{M2}	density of wheel	kg/m^3
$\rho_{n,C}$	normal radius of relative curvature at pitch diameter	mm
$\rho_{n,Y}$	normal radius of relative curvature at point Y	mm
$\rho_{t,Y}$	transverse radius of relative curvature at point Y	mm
$\rho_{t1,Y}$	transverse radius of curvature of pinion at point Y	mm
$\rho_{t2,Y}$	transverse radius of curvature of wheel at point Y	mm
$\rho_{\theta B,Y}$	density of lubricant at local contact temperature	kg/m^3
$\rho_{\theta M}$	density of lubricant at bulk temperature	kg/m^3
ρ_{15}	density of lubricant at 15 °C	kg/m^3
Subscripts to symbols		
Y	Parameter for any contact point Y in the contact area for method A and on the path of contact for method B (all parameters subscript Y has to be calculated with local values).	

4 Example calculation

The following presents examples for the calculation of the safety factor against micropitting, S_λ. Each example is first calculated according to method B and examples 1, 3, and 4 subsequently calculated according to method A. The calculation sequence for method B has been provided to follow a logical approach in relation to the input data. Beside the formulae itself, the formula numbers related to ISO/TR 15144-1 are given.

The examples calculate the safety factor S_λ of a specific gear set when compared to an allowable λ_{GFP} value. For the examples 1, 2, and 4, the permissible specific oil film thickness, λ_{GFP}, was determined from the test result of the lubricant in the FZG-FVA micropitting test.[1] For these calculations medium values for the standard FZG back-to-back test rig and standard test conditions for $K_{H\beta}$ and K_v were used ($K_{H\beta}$ = 1,10 and K_v = 1,05). The calculation of the λ_{GFP} value from the test result of the FZG-FVA micropitting test[1] (method B) is shown exemplary on the basis of the first example. For example 3, the permissible specific oil film thickness, λ_{GFP}, was determined from a bench test.

NOTE The calculations were performed computer-based. If the calculations are performed manually, small differences between the results can appear.

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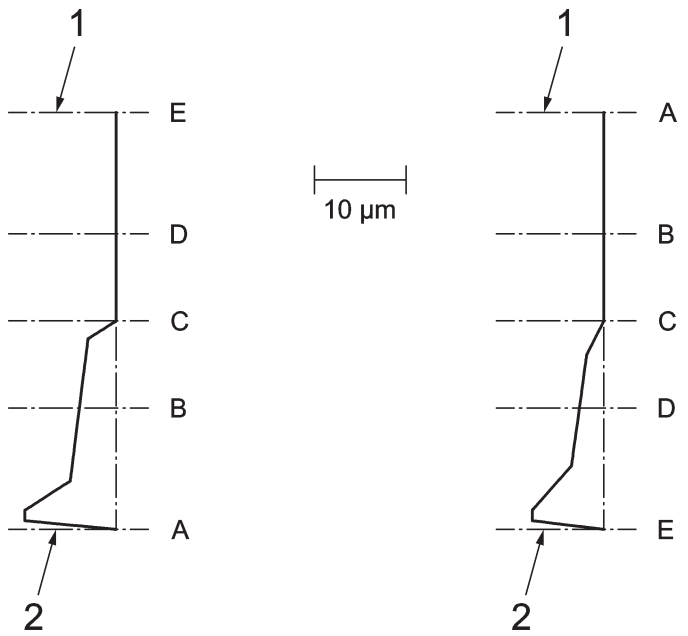
4.1 Example 1 — Spur gear

The result of this example is confirmed by experimental investigations. The gears were obviously micropitted and had profile deviations of approximately 8 to 10 µm. Figure 1 shows a diagram of the observed location and severity of micropitting for pinion and wheel of example 1.



a) pinion **b) wheel**

Key

1 tip

2 root

Figure 1 — Diagram of schematic profile deviations of pinion and wheel for example 1

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4.1.1 Input data

Table 2 — Input data for Example 1

	Symbol	Description	Unit	Example 1	
				pinion	wheel
				comb.	
Geometry	z	number of teeth	-	18	18
	-	driving gear	-	x	
	m_n	normal module	mm	10,93	
	α_n	normal pressure angle	°	20	
	β	helix angle	°	0	
	b	face width	mm	21,4	
	a	centre distance	mm	200	
	x	addendum modification factor	-	0,158	0,158
	d_a	tip diameter of pinion	mm	221,4	221,4
	-	tooth flank modifications	-	no modifications	
	Q	gear quality	-	5	5
	Ra	arithmetic mean roughness value	µm	0,90	0,90
Material	-	material	-	Eh	Eh
	E	modulus of elasticity	N/mm^2	206 000	206 000
	ν	Poisson's ratio	-	0,3	0,3
	λ_M	specific heat conductivity	W/(m·K)	45	45
	c_M	specific heat per unit mass	J/(kg·K)	440	440
	ρ_M	density	kg/m^3	7 800	7 800
	W_w	material factor according to ISO/TR 15144-1:2014, Table A.1 (for matching case carburised/case carburised)	-	1,0	
Application	K_A	application factor	-	1,0	
	K_v	dynamic factor	-	1,15	
	$K_{H\alpha}$	transverse load factor	-	1,0	
	$K_{H\beta}$	face load factor	-	1,10	
Load	T_1	nominal torque at the pinion	Nm	1 878	
	n_1	rotation speed of the pinion	min^{-1}	3 000	
Lubricant	θ_{oil}	oil inlet temperature (injection lubrication)	°C	90	
	ν_{40}	kinematic viscosity at 40 °C	mm^2/s	210	
	ν_{100}	kinematic viscosity at 100 °C	mm^2/s	18,5	
	ρ_{15}	density of the lubricant at 15 °C	kg/m^3	895	
	-	oil type	-	mineral oil	
	-	failure load stage at test temperature (90 °C) according to FVA 54/7	-	SKS 8	
	λ_{GFP}	permissible lubricant film thickness (see 4.1.4 for calculation)	-	0,211	

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4.1.2 Calculation according to method B

4.1.2.1 Calculation of gear geometry (according to ISO 21771)

Basic values:

$$m_t = \frac{m_n}{\cos\beta}$$ m_t = 10,93 mm

$$d_1 = z_1 \cdot m_t$$ d_1 = 196,74 mm

$$d_2 = z_2 \cdot m_t$$ d_2 = 196,74 mm

$$u = \frac{z_2}{z_1}$$ u = 1

$$\alpha_t = \arctan\left(\frac{\tan\alpha_n}{\cos\beta}\right)$$ α_t = 20 °

$$d_{b1} = d_1 \cos\alpha_t$$ d_{b1} = 184,875 mm

$$d_{b2} = d_2 \cos\alpha_t$$ d_{b2} = 184,875 mm

$$d_{w1} = \frac{2 \cdot a}{u+1}$$ d_{w1} = 200 mm

$$d_{w2} = 2 \cdot a - d_{w1}$$ d_{w2} = 200 mm

$$\alpha_{wt} = \arccos\left[\frac{(z_1 + z_2) \cdot m_t \cdot \cos\alpha_t}{2 \cdot a}\right]$$ α_{wt} = 22,426 °

$$\beta_b = \arcsin(\sin\beta \cdot \cos\alpha_n)$$ β_b = 0 ° β_b = 0 °

$$p_{et} = m_t \cdot \pi \cdot \cos\alpha_t$$ p_{et} = 32,267 mm

$$\varepsilon_1 = \frac{z_1}{2 \cdot \pi} \cdot \left[\sqrt{\left(\frac{d_{a1}}{d_{b1}}\right)^2 - 1} - \tan\alpha_{wt}\right]$$ ε_1 = 0,705

$$\varepsilon_2 = \frac{z_2}{2 \cdot \pi} \cdot \left[\sqrt{\left(\frac{d_{a2}}{d_{b2}}\right)^2 - 1} - \tan\alpha_{wt}\right]$$ ε_2 = 0,705

$$\varepsilon_\alpha = \frac{1}{p_{et}} \cdot \left(\sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} + \sqrt{\frac{d_{a2}^2}{4} - \frac{d_{b2}^2}{4}} - a \cdot \sin\alpha_{wt}\right)$$ ε_α = 1,411

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$$\varepsilon_\beta = \frac{b \cdot \sin\beta}{m_n \cdot \pi}$$ $\varepsilon_\beta = 0$

$$\varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta$$ $\varepsilon_\gamma = 1{,}411$

$$g_\alpha = 0{,}5 \cdot \left(\sqrt{d_{a1}^2 - d_{b1}^2} + \sqrt{d_{a2}^2 - d_{b2}^2} \right) - a \cdot \sin\alpha_{wt}$$ $g_\alpha = 45{,}519$ mm

Coordinates of the basic points (A, AB, B, C, D, DE, E) on the line of action:

$$g_A = 0 \text{ mm}$$ (34) $g_A = 0$ mm

$$g_{AB} = \frac{g_\alpha - p_{et}}{2}$$ (35) $g_{AB} = 6{,}626$ mm

$$g_B = g_\alpha - p_{et}$$ (36) $g_B = 13{,}253$ mm

$$g_C = \frac{d_{b1}}{2} \cdot \tan\alpha_{wt} - \sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} + g_\alpha$$ (37) $g_C = 22{,}760$ mm

$$g_D = p_{et}$$ (38) $g_D = 32{,}267$ mm

$$g_{DE} = \frac{g_\alpha - p_{et}}{2} + p_{et}$$ (39) $g_{DE} = 38{,}893$ mm

$$g_E = g_\alpha$$ (40) $g_E = 45{,}519$ mm

$$d_{A1} = 2 \cdot \sqrt{\frac{d_{b1}^2}{4} + \left(\sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} - g_\alpha + g_A \right)^2}$$ (41) $d_{A1} = 187{,}419$ mm

$d_{AB1} = 190{,}046$ mm $d_{B1} = 193{,}546$ mm $d_{C1} = 200{,}000$ mm

$d_{D1} = 207{,}998$ mm $d_{DE1} = 214{,}394$ mm $d_{E1} = 221{,}400$ mm

$$d_{A2} = 2 \cdot \sqrt{\frac{d_{b2}^2}{4} + \left(\sqrt{\frac{d_{a2}^2}{4} - \frac{d_{b2}^2}{4}} - g_A \right)^2}$$ (42) $d_{A2} = 221{,}400$ mm

$d_{AB2} = 214{,}394$ mm $d_{B2} = 207{,}998$ mm $d_{C2} = 200{,}000$ mm

$d_{D2} = 193{,}546$ mm $d_{DE2} = 190{,}046$ mm $d_{E2} = 187{,}419$ mm

Normal radius of relative curvature:

$$\rho_{n,A} = \frac{\rho_{t,A}}{\cos\beta_b}$$ (45) $\rho_{n,A} = 12{,}285$ mm

$\rho_{n,AB} = 15{,}663$ mm $\rho_{n,B} = 17{,}890$ mm $\rho_{n,C} = 19{,}074$ mm

$\rho_{n,D} = 17{,}890$ $\rho_{n,DE} = 15{,}663$ mm $\rho_{n,E} = 12{,}285$ mm

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4.1.2.2 Calculation of material data

$$E_r = 2 \cdot \left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \right)^{-1}$$ (6) E_r = 226 374 N/mm²

$$B_{M1} = \sqrt{\lambda_{M1} \cdot \rho_{M1} \cdot c_{M1}}$$ (82) B_{M1} = 12 427,4 N/(ms^{0,5}K)

$$B_{M2} = \sqrt{\lambda_{M2} \cdot \rho_{M2} \cdot c_{M2}}$$ (83) B_{M2} = 12 427,4 N/(ms^{0,5}K)

4.1.2.3 Calculation of operating conditions

Loading:

$$P = 2 \cdot \pi \cdot \frac{n_1}{60} \cdot \frac{T_1}{1\,000}$$ (85) P = 590 kW

$$F_t = 2\,000 \cdot \frac{T_1}{d_1}$$ F_t = 19 091 N

$$F_{bt} = 2\,000 \cdot \frac{T_1}{d_{b1}}$$ F_{bt} = 20 316 N

Local load sharing factor:

NOTE No tooth flank modifications, spur gears, gear quality ≤7 (see ISO/TR 15144-1:2014, Figure 2).

$$X_A = \frac{Q-2}{15} + \frac{1}{3} \cdot \frac{g_A}{g_B}$$ (46) X_A = 0,333

X_{AB} = 0,500 X_B = 1,000 X_C = 1,000

X_D = 1,000 X_{DE} = 0,500 X_E = 0,333

Elasticity factor:

$$Z_E = \sqrt{\frac{E_r}{2 \cdot \pi}}$$ (26) Z_E = 189,812 (N/mm²)^{0,5}

Local Hertzian contact stress:

$$p_{H,A,B} = Z_E \cdot \sqrt{\frac{F_t \cdot X_A}{b \cdot \rho_{n,A} \cdot \cos\alpha_t \cdot \cos\beta_b}}$$ (25) $p_{H,A,B}$ = 963 N/mm²

$p_{H,AB,B}$ = 1 045 N/mm² $p_{H,B,B}$ = 1 383 N/mm² $p_{H,C,B}$ = 1 339 N/mm²

$p_{H,D,B}$ = 1 383 N/mm² $p_{H,DE,B}$ = 1 045 N/mm² $p_{H,E,B}$ = 963 N/mm²

$$p_{dyn,A,B} = p_{H,A,B} \cdot \sqrt{K_A \cdot K_V \cdot K_{H\alpha} \cdot K_{H\beta}}$$ (24) $p_{dyn,A,B}$ = 1 084 N/mm²

$p_{dyn,AB,B}$ = 1 175 N/mm² $p_{dyn,B,B}$ = 1 555 N/mm² $p_{dyn,C,B}$ = 1 506 N/mm²

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$p_{dyn,D,B}$ = 1 555 N/mm² $p_{dyn,DE,B}$ = 1 175 N/mm² $p_{dyn,E,B}$ = 1 084 N/mm²

Velocity:

$v_{g,A} = v_{r1,A} - v_{r2,A}$ (81) $v_{g,A}$ = –14,300 m/s

$v_{g,AB}$ = –10,137 m/s $v_{g,B}$ = –5,974 m/s $v_{g,C}$ = 0 m/s

$v_{g,D}$ = 5,974 m/s $v_{g,DE}$ = 10,137 m/s $v_{g,E}$ = 14,300 m/s

$v_{\Sigma,A} = v_{r1,A} + v_{r2,A}$ (13) $v_{\Sigma,A}$ = 23,969 m/s

$v_{\Sigma,AB}$ = 23,969 m/s $v_{\Sigma,B}$ = 23,969 m/s $v_{\Sigma,C}$ =23,969 m/s

$v_{\Sigma,D}$ = 23,969 m/s $v_{\Sigma,DE}$ = 23,969 m/s $v_{\Sigma,E}$ =23,969 m/s

Effective arithmetic mean roughness value:

$$Ra = 0{,}5 \cdot \left(Ra_1 + Ra_2\right) \quad (3) \quad Ra = 0{,}90\ \mu m$$

4.1.2.4 Calculation of lubricant data

X_L = 1,0 for mineral oil (see ISO/TR 15144-1:2014, Table 3)

$$\alpha_{38} = 2{,}657 \cdot 10^{-8} \cdot \eta_{38}^{0{,}134\,8} \quad (9) \quad \alpha_{38} = 2{,}15 \cdot 10^{-8}\ m^2/N$$

X_S = 1,2 for injection lubrication

4.1.2.5 Calculation of the material parameter

Mean coefficient of friction:

$$X_R = 2{,}2 \cdot \left(\frac{Ra}{\rho_{n,C}}\right)^{0{,}25} \quad (87) \quad X_R = 1{,}025$$

$K_{B\gamma}$ = 1,0 for ε_γ <2

$$\mu_m = 0{,}045 \cdot \left(\frac{K_A \cdot K_v \cdot K_{H\alpha} \cdot K_{H\beta} \cdot F_{bt} \cdot K_{B\gamma}}{b \cdot v_{\Sigma,C} \cdot \rho_{n,C}}\right)^{0{,}2} \cdot \left(10^3 \cdot \eta_{\theta oil}\right)^{-0{,}05} \cdot X_R \cdot X_L \quad (86) \quad \mu_m = 0{,}048$$

Bulk temperature:

$$H_v = \left(\varepsilon_1^{\,2} + \varepsilon_2^{\,2} + 1 - \varepsilon_\alpha\right) \cdot \left(\frac{1}{z_1} + \frac{1}{z_2}\right) \cdot \frac{\pi}{\cos\beta_b} \text{ for } \varepsilon_\alpha < 2 \quad (91) \quad H_v = 0{,}204$$

$\varepsilon_{max} = \varepsilon_1 = \varepsilon_2$

X_{CA} = 1,0 for no profile modification (method B) (101)

$$\theta_M = \theta_{oil} + 7\,400 \cdot \left(\frac{P \cdot \mu_m \cdot H_v}{a \cdot b}\right)^{0{,}72} \cdot \frac{X_S}{1{,}2 \cdot X_{Ca}} \quad (84) \quad \theta_M = 153{,}6°\ C$$

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