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**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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the 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*

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 cylindrical 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.

Table 1 — Symbols and units

Symbol	Description	Unit
a	centre distance	mm
B_{M1}	thermal contact coefficient of pinion	$N/(m \cdot s^{0,5} \cdot K)$
B_{M2}	thermal contact coefficient of wheel	$N/(m \cdot s^{0,5} \cdot K)$
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	$J/(kg \cdot K)$
c_{M2}	specific heat per unit mass of wheel	$J/(kg \cdot K)$
c'	maximum tooth stiffness per unit face width (single stiffness) of a tooth pair	$N/(mm \cdot \mu m)$
$c_{\gamma\alpha}$	mean value of mesh stiffness per unit face width	$N/(mm \cdot \mu m)$
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
R_a	effective arithmetic mean roughness value	μm
R_{a1}	arithmetic mean roughness value of pinion	μm
R_{a2}	arithmetic mean roughness value of wheel	μm
$S_{GF,Y}$	local sliding parameter	-

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	-
$\epsilon_{\alpha n}$	virtual transverse contact ratio	-
ϵ_β	overlap ratio	-
ϵ_Y	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·s/m ²
$\eta_{\theta M}$	dynamic viscosity at bulk temperature	N·s/m ²
$\eta_{\theta oil}$	dynamic viscosity at oil inlet/sump temperature	N·s/m ²
η_{38}	dynamic viscosity at 38 °C	N·s/m ²
$\theta_{B,Y}$	local contact temperature	°C
$\theta_{fl,Y}$	local flash temperature	°C
θ_M	bulk temperature	°C

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

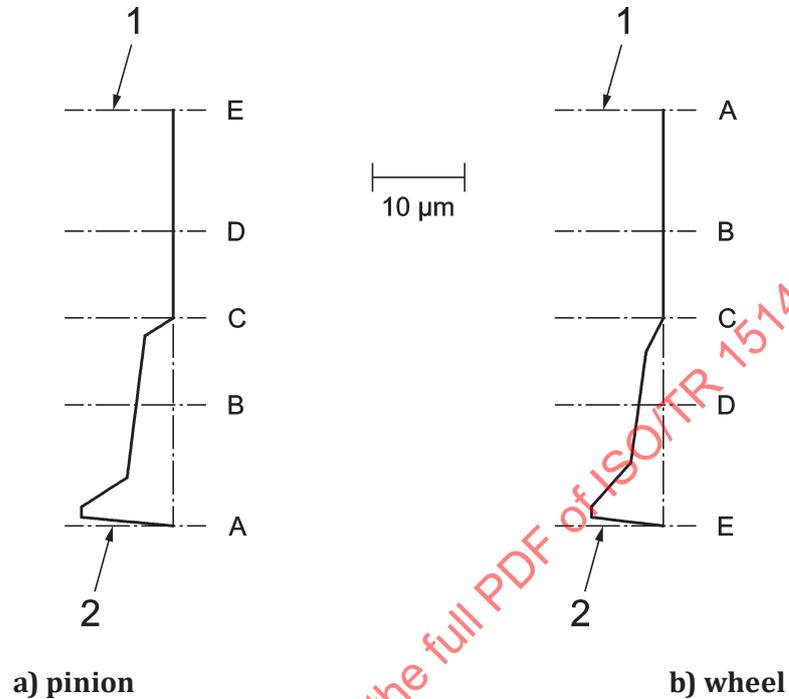
The following presents examples for the calculation of the safety factor against micropitting, S_λ . Each example is first calculated according to method B and examples 1, 3, and 4 subsequently calculated according to method A. The calculation sequence for method B has been provided to follow a logical 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.

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.



Key

- 1 tip
- 2 root

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

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
	R_a	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	

4.1.2 Calculation according to method B

4.1.2.1 Calculation of gear geometry (according to ISO 21771)

Basic values:

$$m_t = \frac{m_n}{\cos \beta}$$

$$m_t = 10,93 \text{ mm}$$

$$d_1 = z_1 \cdot m_t$$

$$d_1 = 196,74 \text{ mm}$$

$$d_2 = z_2 \cdot m_t$$

$$d_2 = 196,74 \text{ mm}$$

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

$$u = 1$$

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

$$\alpha_t = 20^\circ$$

$$d_{b1} = d_1 \cos \alpha_t$$

$$d_{b1} = 184,875 \text{ mm}$$

$$d_{b2} = d_2 \cos \alpha_t$$

$$d_{b2} = 184,875 \text{ mm}$$

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

$$d_{w1} = 200 \text{ mm}$$

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

$$d_{w2} = 200 \text{ mm}$$

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

$$\alpha_{wt} = 22,426^\circ$$

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

$$\beta_b = 0^\circ \quad \beta_b = 0^\circ$$

$$p_{et} = m_t \cdot \pi \cdot \cos \alpha_t$$

$$p_{et} = 32,267 \text{ mm}$$

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

$$\varepsilon_1 = 0,705$$

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

$$\varepsilon_2 = 0,705$$

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

$$\varepsilon_\alpha = 1,411$$

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

$$\varepsilon_{\beta} = 0$$

$$\varepsilon_{\gamma} = \varepsilon_{\alpha} + \varepsilon_{\beta}$$

$$\varepsilon_{\gamma} = 1,411$$

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

$$g_{\alpha} = 45,519 \text{ mm}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Normal radius of relative curvature:

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

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

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

4.1.2.2 Calculation of material data

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

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

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

4.1.2.3 Calculation of operating conditions

Loading:

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

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

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

Local load sharing factor:

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

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

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

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

Elasticity factor:

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

Local Hertzian contact stress:

$$p_{H,A,B} = Z_E \cdot \sqrt{\frac{F_t \cdot X_A}{b \cdot \rho_{n,A} \cdot \cos \alpha_t \cdot \cos \beta_b}} \quad (25) \quad p_{H,A,B} = 963 \text{ N/mm}^2$$

$$p_{H,AB,B} = 1\,045 \text{ N/mm}^2 \quad p_{H,B,B} = 1\,383 \text{ N/mm}^2 \quad p_{H,C,B} = 1\,339 \text{ N/mm}^2$$

$$p_{H,D,B} = 1\,383 \text{ N/mm}^2 \quad p_{H,DE,B} = 1\,045 \text{ N/mm}^2 \quad p_{H,E,B} = 963 \text{ N/mm}^2$$

$$p_{\text{dyn},A,B} = p_{H,A,B} \cdot \sqrt{K_A \cdot K_V \cdot K_{H\alpha} \cdot K_{H\beta}} \quad (24) \quad p_{\text{dyn},A,B} = 1\,084 \text{ N/mm}^2$$

$$p_{\text{dyn},AB,B} = 1\,175 \text{ N/mm}^2 \quad p_{\text{dyn},B,B} = 1\,555 \text{ N/mm}^2 \quad p_{\text{dyn},C,B} = 1\,506 \text{ N/mm}^2$$

$$p_{\text{dyn},D,B} = 1\,555 \text{ N/mm}^2 \quad p_{\text{dyn},DE,B} = 1\,175 \text{ N/mm}^2 \quad p_{\text{dyn},E,B} = 1\,084 \text{ N/mm}^2$$

Velocity:

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

$$v_{g,AB} = -10,137 \text{ m/s} \quad v_{g,B} = -5,974 \text{ m/s} \quad v_{g,C} = 0 \text{ m/s}$$

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

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

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

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

Effective arithmetic mean roughness value:

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

4.1.2.4 Calculation of lubricant data

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

$$\alpha_{38} = 2,657 \cdot 10^{-8} \cdot \eta_{38}^{0,1348} \quad (9) \quad \alpha_{38} = 2,15 \cdot 10^{-8} \text{ m}^2 / \text{N}$$

$X_S = 1,2$ for injection lubrication

4.1.2.5 Calculation of the material parameter

Mean coefficient of friction:

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

$K_{By} = 1,0$ for $\varepsilon_\gamma < 2$

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

Bulk temperature:

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

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

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

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

Material parameter:

$$G_M = 10^6 \cdot \alpha_{\theta M} \cdot E_r \quad (5) \quad G_M = 2\,678,6$$

4.1.2.6 Calculation of the velocity parameter

$$U_A = \eta_{\theta M} \cdot \frac{v_{\Sigma,A}}{2000 \cdot E_r \cdot \rho_{n,A}} \quad (12) \quad U_A = 2,005 \cdot 10^{-11}$$

$$U_{AB} = 1,572 \cdot 10^{-11} \quad U_B = 1,377 \cdot 10^{-11} \quad U_C = 1,291 \cdot 10^{-11}$$

$$U_D = 1,377 \cdot 10^{-11} \quad U_{DE} = 1,572 \cdot 10^{-11} \quad U_E = 2,005 \cdot 10^{-11}$$

4.1.2.7 Calculation of the load parameter

$$W_A = \frac{2 \cdot \pi \cdot p_{\text{dyn},A}^2}{E_r^2} \quad (22) \quad W_A = 1,440 \cdot 10^{-4}$$

$$W_{AB} = 1,694 \cdot 10^{-4} \quad W_B = 2,966 \cdot 10^{-4} \quad W_C = 2,781 \cdot 10^{-4}$$

$$W_D = 2,966 \cdot 10^{-4} \quad W_{DE} = 1,694 \cdot 10^{-4} \quad W_E = 1,440 \cdot 10^{-4}$$

4.1.2.8 Calculation of the sliding parameter

Local flash temperature:

$$\theta_{fl,A} = \frac{\sqrt{\pi}}{2} \cdot \frac{10^6 \cdot \mu_m \cdot p_{\text{dyn},A} \cdot |v_{g,A}|}{B_{M1} \sqrt{v_{r1,A}} + B_{M2} \sqrt{v_{r2,A}}} \cdot \sqrt{8 \cdot \rho_{n,A} \cdot \frac{p_{\text{dyn},A}}{1000 \cdot E_r}} \quad (80) \quad \theta_{fl,A} = 175,3^\circ \text{C}$$

$$\theta_{fl,AB} = 154,1^\circ \text{C} \quad \theta_{fl,B} = 145,4^\circ \text{C} \quad \theta_{fl,C} = 0^\circ \text{C}$$

$$\theta_{fl,D} = 145,4^\circ \text{C} \quad \theta_{fl,DE} = 154,1^\circ \text{C} \quad \theta_{fl,E} = 175,3^\circ \text{C}$$

Local contact temperature as sum of bulk and local flash temperature:

$$\theta_{B,A} = \theta_M + \theta_{fl,A} \quad (79) \quad \theta_{B,A} = 328,9^\circ \text{C}$$

$$\theta_{B,AB} = 307,7^\circ \text{C} \quad \theta_{B,B} = 299,0^\circ \text{C} \quad \theta_{B,C} = 153,6^\circ \text{C}$$

$$\theta_{B,D} = 299,0^\circ \text{C} \quad \theta_{B,DE} = 307,7^\circ \text{C} \quad \theta_{B,E} = 328,9^\circ \text{C}$$

Local sliding parameter:

$$S_{GF,A} = \frac{\alpha_{\theta B,A} \cdot \eta_{\theta B,A}}{\alpha_{\theta M} \cdot \eta_{\theta M}} \quad (27) \quad S_{GF,A} = 0,057$$

$$S_{GF,AB} = 0,076 \quad S_{GF,B} = 0,086 \quad S_{GF,C} = 1,000$$

$$S_{GF,D} = 0,086 \quad S_{GF,DE} = 0,076 \quad S_{GF,E} = 0,057$$

4.1.2.9 Calculation of the lubricant film thickness

$$h_A = 1600 \cdot \rho_{n,A} \cdot G_M^{0,6} \cdot U_A^{0,7} \cdot W_A^{-0,13} \cdot S_{GF,A}^{0,22} \quad (4) \quad h_A = 0,122 \mu\text{m}$$

$$\begin{aligned}
 h_{AB} &= 0,137 \text{ }\mu\text{m} & h_B &= 0,136 \text{ }\mu\text{m} & h_C &= 0,241 \text{ }\mu\text{m} \\
 h_D &= 0,136 \text{ }\mu\text{m} & h_{DE} &= 0,137 \text{ }\mu\text{m} & h_E &= 0,122 \text{ }\mu\text{m}
 \end{aligned}$$

4.1.2.10 Calculation of the specific lubricant film thickness

$$\lambda_{GF,A} = \frac{h_A}{Ra} \tag{2} \quad \lambda_{GF,A} = 0,136$$

$$\lambda_{GF,AB} = 0,153 \quad \lambda_{GF,B} = 0,152 \quad \lambda_{GF,C} = 0,267$$

$$\lambda_{GF,D} = 0,152 \quad \lambda_{GF,DE} = 0,153 \quad \lambda_{GF,E} = 0,136$$

$$\lambda_{GF,min} = \lambda_{GF,A} = \lambda_{GF,E} \quad \lambda_{GF,min} = 0,136$$

4.1.2.11 Calculation of the micropitting safety factor

$$S_\lambda = \frac{\lambda_{GF,min}}{\lambda_{GFP}} \tag{1} \quad S_\lambda = 0,644$$

The calculation of the permissible specific lubricant film thickness, λ_{GFP} , for example 1 is shown exemplary in 4.1.4.

The final results for the calculation of the safety factor against micropitting, S_λ , for example 1 are shown in Table 3.

Table 3 — Results of calculation according to method B — Example 1

Point	A	AB	B	C	D	DE	E
$\lambda_{GF,Y}$	0,136	0,153	0,152	0,267	0,152	0,153	0,136
$\lambda_{GF,min}$	0,136						
λ_{GFP}	0,211						
S_λ	0,644						

4.1.3 Calculation according to method A

The calculation of example 1 according to method A was carried out by a 3D-calculation programme. Calculated results during method A will vary depending on the method of determining load distribution. The load distribution, on which the following calculation according to method A is based, is shown in Table 4. The maximum values are printed in bold.

Table 4 — Matrix of pressure distribution — $p_{H,Y,A}$ in N/mm²

	Width in mm			
	0,0	7,6	13,8	21,4
A	1 115	1 110	1 110	1 114
AB	1 048	1 044	1 044	1 047
B	1 375	1 373	1 373	1 375
C	1 342	1 339	1 339	1 342
D	1 048	1 045	1 045	1 048
DE	1 050	1 046	1 046	1 050
E	1 099	1 094	1 094	1 099

The resulting matrix of specific lubricant film thickness according to method A is shown in [Table 5](#). The minimum value is printed in bold.

Table 5 — Matrix of resulting specific lubricant film thickness $\lambda_{GF,Y}$

	Width in mm			
	0,0	7,6	13,8	21,4
A	0,122	0,123	0,123	0,122
AB	0,159	0,160	0,160	0,159
B	0,159	0,159	0,159	0,159
C	0,270	0,271	0,271	0,270
D	0,197	0,198	0,198	0,197
DE	0,159	0,159	0,159	0,159
E	0,124	0,125	0,125	0,124

For the calculation of the micropitting safety factor according to method A, the minimum value of the matrix of resulting specific lubricant film thickness, shown in [Table 5](#), was used.

$$S_{\lambda} = \frac{\lambda_{GF,min}}{\lambda_{GFP}} \quad (1) \quad S_{\lambda} = 0,577$$

NOTE The difference in safety factor calculated between methods A and B in the above example 1 results from the simplified calculation of load distribution according to method B.

4.1.4 Calculation of the permissible lubricant film thickness

Calculation of the permissible specific lubricant film thickness from the test result of the FZG-FVA micropitting test^[1] (Method B) with the reference test gears type C-GF.

The calculation of the reference value, λ_{GFT} , is done for point A because the minimum specific lubricant film thickness for gear type C is always at point A. All data of the reference test gears type C-GF have the subscript "Ref".

Table 6 — Input data for calculation of the permissible lubricant film thickness

	Symbol	Description	Unit	C-GF	
				pinion	wheel
				comb.	
Geometry	z_{Ref}	number of teeth	-	16	24
	m_{tRef}	transverse module ($m_{nRef} = m_{tRef}$)	mm	4,5	
	α_{nRef}	transverse pressure angle ($\alpha_{nRef} = \alpha_{tRef}$)	°	20	
	β_{bRef}	base helix angle ($\beta_{bRef} = \beta_{Ref}$)	°	0	
	b_{Ref}	face width	mm	14	
	a_{Ref}	centre distance	mm	91,5	
	x_{Ref}	addendum modification factor	-	0,1817	0,1716
	d_{aRef}	tip diameter of pinion	mm	82,45	118,35
	-	tooth flank modifications	-	no modifications	
	R_{aRef}	arithmetic mean roughness value	µm	0,50	0,50
	E_{Ref}	modulus of elasticity	N/mm ²	206 000	206 000
	ν_{Ref}	Poisson's ratio		0,3	0,3
	λ_{MRef}	specific heat conductivity	W/(m·K)	45	45
	c_{MRef}	specific heat per unit mass	J/(kg·K)	440	440
	ρ_{MRef}	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_{ARef}	application factor	-	1,0	
	K_{VRef}	dynamic factor	-	1,05	
	$K_{H\alpha Ref}$	transverse load factor	-	1,0	
	$K_{H\beta Ref}$	face load factor	-	1,10	
Load	T_{1Ref}	nominal torque at the pinion for SKS 8	Nm	171,6	
	n_{1Ref}	rotation speed of the pinion	min ⁻¹	2 250	
	$p_{H,A,A}$	nominal Hertzian contact stress at point A according to method A for SKS 8 (see Table 6)	N/mm ²	1 191	
	-	lubrication	-	injection lubrication	

NOTE The used values for K_{VRef} and $K_{H\beta Ref}$ are valid for the standard FZG back-to-back test rig and standard conditions.

Table 7 gives the nominal Hertzian contact stress at point A for the reference test gears type C-GF as a function of the reached failure load stage (SKS) in the FZG-FVA micropitting test.[1]

Table 7 — Relation between failure load stage according to FZG-FVA micropitting test¹⁾ and nominal Hertzian contact stress at point A

SKS	Nominal torque at the pinion in Nm	Hertzian contact stress at point C in N/mm ²	Nominal Hertzian contact stress at point A according to method A
5	70,0	795,1	764
6	98,9	945,1	906
7	132,5	1 093,9	1 048
8	171,6	1 244,9	1 191
9	215,6	1 395,4	1 333
10	265,1	1 547,3	1 476

4.1.4.1 Calculation of gear geometry

$$d_{1Ref} = z_{1Ref} \cdot m_{tRef}$$

$$d_{1Ref} = 72,00 \text{ mm}$$

$$d_{2Ref} = z_{2Ref} \cdot m_{tRef}$$

$$d_{2Ref} = 108,00 \text{ mm}$$

$$u_{Ref} = \frac{z_{2Ref}}{z_{1Ref}}$$

$$u_{Ref} = 1,5$$

$$d_{b1Ref} = d_{1Ref} \cdot \cos \alpha_{tRef}$$

$$d_{b1Ref} = 67,658 \text{ mm}$$

$$d_{b2Ref} = d_{2Ref} \cdot \cos \alpha_{tRef}$$

$$d_{b2Ref} = 101,487 \text{ mm}$$

$$d_{w1Ref} = \frac{2 \cdot a_{Ref}}{u_{Ref} + 1}$$

$$d_{w1Ref} = 73,20 \text{ mm}$$

$$d_{w2Ref} = 2 \cdot a_{Ref} - d_{w1Ref}$$

$$d_{w2Ref} = 109,80 \text{ mm}$$

$$\alpha_{wtRef} = \arccos \left[\frac{(z_{1Ref} + z_{2Ref}) \cdot m_{tRef} \cdot \cos \alpha_{tRef}}{2 \cdot a_{Ref}} \right]$$

$$\alpha_{wtRef} = 22,439^\circ$$

$$p_{etRef} = m_{tRef} \cdot \pi \cdot \cos \alpha_{tRef}$$

$$p_{etRef} = 13,285 \text{ mm}$$

$$\varepsilon_{1Ref} = \frac{z_{1Ref}}{2 \cdot \pi} \cdot \left[\sqrt{\left(\frac{d_{a1Ref}}{d_{b1Ref}} \right)^2 - 1} - \tan \alpha_{wtRef} \right]$$

$$\varepsilon_{1Ref} = 0,722$$

$$\varepsilon_{2Ref} = \frac{z_{2Ref}}{2 \cdot \pi} \cdot \left[\sqrt{\left(\frac{d_{a2Ref}}{d_{b2Ref}} \right)^2 - 1} - \tan \alpha_{wtRef} \right]$$

$$\varepsilon_{2Ref} = 0,714$$

$$\varepsilon_{\alpha\text{Ref}} = \frac{1}{p_{\text{etRef}}} \cdot \left(\sqrt{\frac{d_{a1\text{Ref}}^2}{4} - \frac{d_{b1\text{Ref}}^2}{4}} + \sqrt{\frac{d_{a2\text{Ref}}^2}{4} - \frac{d_{b2\text{Ref}}^2}{4}} - a_{\text{Ref}} \cdot \sin \alpha_{\text{wtRef}} \right) \varepsilon_{\alpha\text{Ref}} = 1,436$$

$$\varepsilon_{\beta\text{Ref}} = \frac{b_{\text{Ref}} \cdot \sin \beta_{\text{Ref}}}{m_{n\text{Ref}} \cdot \pi} \quad \varepsilon_{\text{Ref}} = 0$$

$$\varepsilon_{\gamma\text{Ref}} = \varepsilon_{\alpha\text{Ref}} + \varepsilon_{\beta\text{Ref}} \quad \varepsilon_{\gamma\text{Ref}} = 1,436$$

$$g_{\alpha\text{Ref}} = 0,5 \cdot \left(\sqrt{d_{a1\text{Ref}}^2 - d_{b1\text{Ref}}^2} + \sqrt{d_{a2\text{Ref}}^2 - d_{b2\text{Ref}}^2} \right) - a_{\text{Ref}} \cdot \sin \alpha_{\text{wtRef}} \quad g_{\alpha\text{Ref}} = 19,079 \text{ mm}$$

$$g_{\text{ARef}} = 0 \text{ mm} \quad (34) \quad g_{\text{ARef}} = 0 \text{ mm}$$

$$d_{\text{A1Ref}} = 2 \cdot \sqrt{\frac{d_{b1\text{Ref}}^2}{4} + \left(\sqrt{\frac{d_{a1\text{Ref}}^2}{4} - \frac{d_{b1\text{Ref}}^2}{4}} - g_{\alpha\text{Ref}} + g_{\text{ARef}} \right)^2} \quad (41) \quad d_{\text{A1Ref}} = 68,249 \text{ mm}$$

$$d_{\text{A2Ref}} = 2 \cdot \sqrt{\frac{d_{b2\text{Ref}}^2}{4} + \left(\sqrt{\frac{d_{a2\text{Ref}}^2}{4} - \frac{d_{b2\text{Ref}}^2}{4}} - g_{\alpha\text{Ref}} \right)^2} \quad (42) \quad d_{\text{A2Ref}} = 118,350 \text{ mm}$$

$$\rho_{t1,\text{ARef}} = \sqrt{\frac{d_{\text{A1Ref}}^2 - d_{b1\text{Ref}}^2}{4}} \quad (44) \quad \rho_{t1,\text{ARef}} = 4,482 \text{ mm}$$

$$\rho_{t1,\text{CRef}} = \sqrt{\frac{d_{w1\text{Ref}}^2 - d_{b1\text{Ref}}^2}{4}} \quad (44) \quad \rho_{t1,\text{CRef}} = 13,970 \text{ mm}$$

$$\rho_{t2,\text{ARef}} = \sqrt{\frac{d_{\text{A2Ref}}^2 - d_{b2\text{Ref}}^2}{4}} \quad (44) \quad \rho_{t2,\text{ARef}} = 30,443 \text{ mm}$$

$$\rho_{t2,\text{CRef}} = \sqrt{\frac{d_{w2\text{Ref}}^2 - d_{b2\text{Ref}}^2}{4}} \quad (44) \quad \rho_{t2,\text{CRef}} = 20,955 \text{ mm}$$

$$\rho_{t,\text{ARef}} = \frac{\rho_{t1,\text{ARef}} \cdot \rho_{t2,\text{ARef}}}{\rho_{t1,\text{ARef}} + \rho_{t2,\text{ARef}}} \quad (43) \quad \rho_{t,\text{ARef}} = \rho_{n,\text{ARef}} = 3,907 \text{ mm}$$

$$\rho_{t,\text{CRef}} = \frac{\rho_{t1,\text{CRef}} \cdot \rho_{t2,\text{CRef}}}{\rho_{t1,\text{CRef}} + \rho_{t2,\text{CRef}}} \quad (43) \quad \rho_{t,\text{CRef}} = \rho_{n,\text{CRef}} = 8,382 \text{ mm}$$

4.1.4.2 Calculation of material data type C-GF

$$E_{rRef} = 2 \cdot \left(\frac{1 - \nu_{1Ref}^2}{E_{1Ref}} + \frac{1 - \nu_{2Ref}^2}{E_{2Ref}} \right)^{-1} \quad (6) \quad E_{rRef} = 226\,374 \text{ N/mm}^2$$

$$B_{M1Ref} = \sqrt{\lambda_{M1Ref} \cdot \rho_{M1Ref} \cdot c_{M1Ref}} \quad (82) \quad B_{M1Ref} = 12\,427,4 \text{ N/(ms}^{0,5}\text{K)}$$

$$B_{M2Ref} = \sqrt{\lambda_{M2Ref} \cdot \rho_{M2Ref} \cdot c_{M2Ref}} \quad (83) \quad B_{M2Ref} = 12\,427,4 \text{ N/(ms}^{0,5}\text{K)}$$

4.1.4.3 Calculation of operating conditions of FVA-FZG micropitting test

$$P_{Ref} = 2 \cdot \pi \cdot \frac{n_{1Ref}}{60} \cdot \frac{T_{1Ref}}{1000} \quad (85) \quad P_{Ref} = 40,43 \text{ kW}$$

$$F_{btRef} = 2000 \cdot \frac{T_{1Ref}}{d_{b1Ref}} \quad F_{btRef} = 5\,072,6 \text{ N}$$

$$p_{dyn,A,ARef} = p_{H,A,ARef} \cdot \sqrt{K_{ARef} \cdot K_{vRef}} \quad (24) \quad p_{dyn,A,ARef} = 1\,220 \text{ N/mm}^2$$

$$v_{r1,ARef} = 2 \cdot \pi \cdot \frac{n_{1Ref}}{60} \cdot \frac{d_{w1Ref}}{2000} \cdot \sin \alpha_{wtRef} \cdot \sqrt{\frac{d_{A1Ref}^2 - d_{b1Ref}^2}{d_{w1Ref}^2 - d_{b1Ref}^2}} \quad (14) \quad v_{r1,ARef} = 1,056 \text{ m/s}$$

$$v_{r1,CRef} = 2 \cdot \pi \cdot \frac{n_{1Ref}}{60} \cdot \frac{d_{w1Ref}}{2000} \cdot \sin \alpha_{wtRef} \quad (14) \quad v_{r1,CRef} = 3,292 \text{ m/s}$$

$$v_{r2,ARef} = 2 \cdot \pi \cdot \frac{n_{1Ref}}{60 \cdot u_{Ref}} \cdot \frac{d_{w2Ref}}{2000} \cdot \sin \alpha_{wtRef} \cdot \sqrt{\frac{d_{A2Ref}^2 - d_{b2Ref}^2}{d_{w2Ref}^2 - d_{b2Ref}^2}} \quad (15) \quad v_{r2,ARef} = 4,782 \text{ m/s}$$

$$v_{r2,CRef} = 2 \cdot \pi \cdot \frac{n_{1Ref}}{60 \cdot u_{Ref}} \cdot \frac{d_{w2Ref}}{2000} \cdot \sin \alpha_{wtRef} \quad (15) \quad v_{r2,CRef} = 3,292 \text{ m/s}$$

$$v_{g,ARef} = v_{r1,ARef} - v_{r2,ARef} \quad (81) \quad v_{g,ARef} = -3,726 \text{ m/s}$$

$$v_{\Sigma,ARef} = v_{r1,ARef} + v_{r2,ARef} \quad (13) \quad v_{\Sigma,ARef} = 5,838 \text{ m/s}$$

$$v_{\Sigma,CRef} = v_{r1,CRef} + v_{r2,CRef} \quad (13) \quad v_{\Sigma,CRef} = 6,583 \text{ m/s}$$

$$Ra_{Ref} = 0,5 \cdot (Ra_{1Ref} + Ra_{2Ref}) \quad (3) \quad Ra_{Ref} = 0,50 \mu\text{m}$$

4.1.4.4 Calculation of lubricant data

$$\theta_{oilRef} = \theta_{oil} = 90 \text{ }^\circ\text{C}$$

$$\eta_{\theta_{oilRef}} = \eta_{\theta_{oil}} = 0,021 \text{ N}\cdot\text{s/m}^2$$

$X_{SRef} = 1,2$ for injection lubrication

4.1.4.5 Calculation of the permissible specific lubricant film thickness

$$X_{RRef} = 2,2 \cdot \left(\frac{Ra_{Ref}}{\rho_{n,CRef}} \right)^{0,25} \quad (87) \quad X_{RRef} = 1,087$$

$$K_{B\gamma Ref} = 1,0 \text{ for } \varepsilon_\gamma < 2 \quad (88)$$

$$\Pi K_{Ref} = K_{ARef} \cdot K_{VRef} \cdot K_{H\alpha Ref} \cdot K_{H\beta Ref} \cdot K_{B\gamma Ref} \quad \Pi K_{Ref} = 1,155$$

$$\mu_{mRef} = 0,045 \cdot \left(\frac{\prod K_{Ref} \cdot F_{btRef}}{b_{Ref} \cdot v_{\Sigma,CRef} \cdot \rho_{n,CRef}} \right)^{0,2} \cdot \left(10^3 \cdot \eta_{oilRef} \right)^{-0,05} \cdot X_{RRef} \cdot X_L \quad (86) \quad \mu_{mRef} = 0,063$$

$$H_{vRef} = \left(\varepsilon_{1Ref}^2 + \varepsilon_{2Ref}^2 + 1 - \varepsilon_{\alpha Ref} \right) \cdot \left(\frac{1}{z_{1Ref}} + \frac{1}{z_{2Ref}} \right) \cdot \frac{\pi}{\cos \beta_{bRef}} \text{ for } \varepsilon_\alpha < 2 \quad (91) \quad H_{vRef} = 0,195$$

$$X_{CaRef} = 1,0 \text{ for no profile modification (method B)} \quad (101)$$

$$\theta_{MRef} = \theta_{oilRef} + 7400 \cdot \left(\frac{P_{Ref} \cdot \mu_{mRef} \cdot H_{vRef}}{a_{Ref} \cdot b_{Ref}} \right)^{0,72} \cdot \frac{X_{SRef}}{1,2 \cdot X_{CaRef}} \quad (84) \quad \theta_{MRef} = 115,9 \text{ }^\circ\text{C}$$

$$\log[\log(v_{\theta MRef} + 0,7)] = A \cdot \log(\theta_{MRef} + 273) + B \quad (17) \quad v_{\theta MRef} = 12,317 \text{ mm}^2/\text{s}$$

$$\rho_{\theta MRef} = \rho_{15} \cdot \left[1 - 0,7 \cdot \frac{(\theta_{MRef} + 273) - 289}{\rho_{15}} \right] \quad (20) \quad \rho_{\theta MRef} = 825,1 \text{ kg/m}^3$$

$$\eta_{\theta MRef} = 10^{-6} \cdot v_{\theta MRef} \cdot \rho_{\theta MRef} \quad (16) \quad \eta_{\theta MRef} = 0,010 \text{ N}\cdot\text{s/m}^2$$

$$\alpha_{\theta MRef} = \alpha_{38} \cdot \left[1 + 516 \cdot \left(\frac{1}{\theta_{MRef} + 273} - \frac{1}{311} \right) \right] \quad (8) \quad \alpha_{\theta MRef} = 1,436 \cdot 10^{-8} \text{ m}^2/\text{N}$$

$$G_{MRef} = 10^6 \cdot \alpha_{\theta MRef} \cdot E_{rRef} \quad (5) \quad G_{MRef} = 3\,249,9$$

$$U_{ARef} = \eta_{\theta MRef} \cdot \frac{v_{\Sigma,ARef}}{2000 \cdot E_{rRef} \cdot \rho_{n,ARef}} \quad (12) \quad U_{ARef} = 3,354 \cdot 10^{-11}$$

$$W_{ARef} = \frac{2 \cdot \pi \cdot p_{dyn,ARef}^2}{E_{rRef}^2} \quad (22) \quad W_{ARef} = 1,825 \cdot 10^{-4}$$

$$\theta_{fl,ARef} = \frac{\sqrt{\pi}}{2} \cdot \frac{10^6 \cdot \mu_{mRef} \cdot p_{dyn,ARef} \cdot |v_{g,ARef}|}{B_{M1Ref} \sqrt{v_{r1,ARef}} + B_{M2Ref} \sqrt{v_{r2,ARef}}} \cdot \sqrt{8 \cdot \rho_{n,ARef} \cdot \frac{p_{dyn,ARef}}{1000 \cdot E_{rRef}}} \quad (80) \quad \theta_{fl,ARef} = 82,5 \text{ } ^\circ\text{C}$$

$$\theta_{B,ARef} = \theta_{MRef} + \theta_{fl,ARef} \quad (79) \quad \theta_{B,ARef} = 198,3 \text{ } ^\circ\text{C}$$

$$\log[\log(v_{\theta B,ARef} + 0,7)] = A \cdot \log(\theta_{B,ARef} + 273) + B \quad (30) \quad v_{\theta B,ARef} = 3,112 \text{ mm}^2/\text{s}$$

$$\rho_{\theta B,ARef} = \rho_{15} \cdot \left[1 - 0,7 \cdot \frac{(\theta_{B,ARef} + 273) - 289}{\rho_{15}} \right] \quad (33) \quad \rho_{\theta B,ARef} = 7674 \text{ kg/m}^3$$

$$\eta_{\theta B,ARef} = 10^{-6} \cdot v_{\theta B,ARef} \cdot \rho_{\theta B,ARef} \quad (29) \quad \eta_{\theta B,ARef} = 0,002 \text{ N}\cdot\text{s/m}^2$$

$$\alpha_{\theta B,ARef} = \alpha_{38} \cdot \left[1 + 516 \cdot \left(\frac{1}{\theta_{B,ARef} + 273} - \frac{1}{311} \right) \right] \quad (28) \quad \alpha_{\theta B,ARef} = 9,364 \cdot 10^{-9} \text{ m}^2/\text{N}$$

$$S_{GF,ARef} = \frac{\alpha_{\theta B,ARef} \cdot \eta_{\theta B,ARef}}{\alpha_{\theta MRef} \cdot \eta_{\theta MRef}} \quad (27) \quad S_{GF,ARef} = 0,153$$

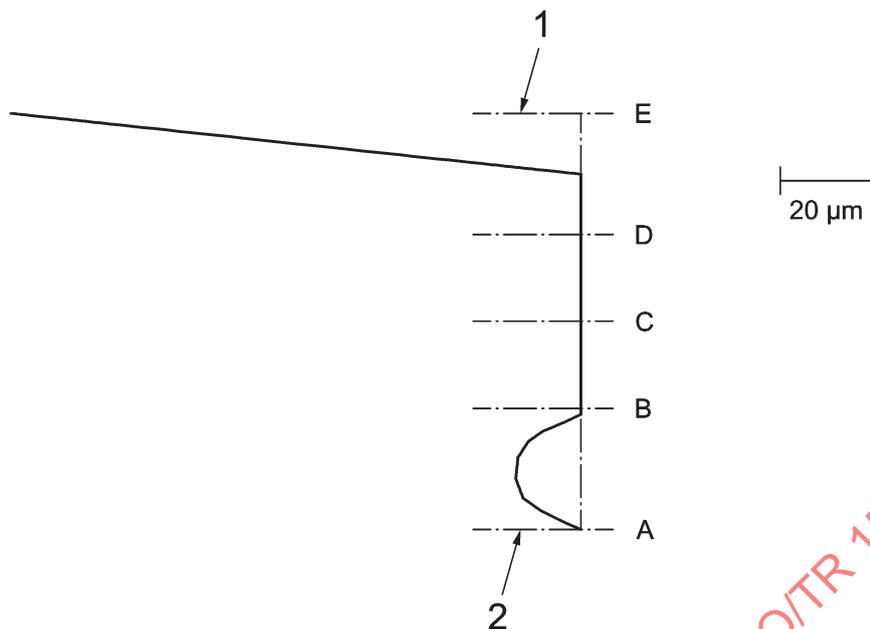
$$h_{ARef} = 1600 \cdot \rho_{n,ARef} \cdot G_{MRef}^{0,6} \cdot U_{ARef}^{0,7} \cdot W_{ARef}^{0,13} \cdot S_{GF,ARef}^{0,22} \quad (4) \quad h_{ARef} = 0,075 \text{ } \mu\text{m}$$

$$\lambda_{GFT} = \lambda_{GF,ARef} = \frac{h_{ARef}}{Ra_{Ref}} \quad (2) \quad \lambda_{GFT} = 0,151$$

$$\lambda_{GFP} = 1,4 \cdot W_W \cdot \lambda_{GFT} \quad \lambda_{GFP} = 0,211$$

4.2 Example 2 — Spur gear

The result of this example is confirmed by experimental investigations. The gears were obviously micropitted and had profile deviations of approximately 15 μm . [Figure 2](#) shows a diagram of the observed location and severity of micropitting for the pinion of example 2.



Key

- 1 tip
- 2 root

Figure 2 — Diagram of schematic profile deviations of the pinion for example 2

NOTE Example 2 is only calculated according to method B. Furthermore, no modifications for the calculation according to method B were considered.

4.2.1 Input data

Table 8 — Input data for Example 2

	Symbol	Description	Unit	Example 2	
				pinion	wheel
				comb.	
Geometry	z	number of teeth	-	20	20
	-	driving gear	-	x	
	m_n	normal module	mm	10,0	
	α_n	normal pressure angle	°	20	
	β	helix angle	°	0	
	b	face width	mm	15	
	a	centre distance	mm	200	
	x	addendum modification factor	-	0,0	0,0
	d_a	tip diameter of pinion	mm	220,0	220,0
	-	tooth flank modifications	-	no adequate tip relief	
	Q	gear quality	-	6	6
R_a	arithmetic mean roughness value	μm	0,80	0,80	

Table 8 (continued)

	Symbol	Description	Unit	Example 2	
				pinion	wheel
				comb.	
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	-	1,038	
	$K_{H\alpha}$	transverse load factor	-	1,0	
	$K_{H\beta}$	face load factor	-	1,05	
Load	T_1	nominal torque at the pinion	Nm	2 400	
	n_1	rotation speed of the pinion	min ⁻¹	1 000	
Lubricant	θ_{oil}	oil inlet temperature (injection lubrication)	°C	70	
	ν_{40}	kinematic viscosity at 40 °C	mm ² /s	150	
	ν_{100}	kinematic viscosity at 100 °C	mm ² /s	14,7	
	ρ_{15}	density of the lubricant at 15 °C	kg/m ³	890	
	-	oil type	-	mineral oil	
	-	failure load stage at test temperature (70 °C) according to FVA 54/7	-	SKS 10	
	λ_{GFP}	permissible lubricant film thickness	-	0,171	

4.2.2 Calculation according to method B

4.2.2.1 Calculation of gear geometry (according to ISO 21771)

Basic values:

$$m_t = \frac{m_n}{\cos \beta}$$

$$m_t = 10,000 \text{ mm}$$

$$d_1 = z_1 \cdot m_t$$

$$d_1 = 200,000 \text{ mm}$$

$$d_2 = z_2 \cdot m_t$$

$$d_2 = 200,000 \text{ mm}$$

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

$$u = 1,00$$

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

$$\alpha_t = 20,000^\circ$$

$$d_{b1} = d_1 \cdot \cos \alpha_t$$

$$d_{b1} = 187,939 \text{ mm}$$

$$d_{b2} = d_2 \cdot \cos \alpha_t$$

$$d_{b2} = 187,939 \text{ mm}$$

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

$$d_{w1} = 200,000 \text{ mm}$$

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

$$d_{w2} = 200,000 \text{ mm}$$

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

$$\alpha_{wt} = 20,000^\circ$$

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

$$\beta_b = 0^\circ$$

$$p_{et} = m_t \cdot \pi \cdot \cos \alpha_t$$

$$p_{et} = 29,521 \text{ mm}$$

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

$$\varepsilon_1 = 0,778$$

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

$$\varepsilon_2 = 0,778$$

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

$$\varepsilon_\alpha = 1,557$$

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

$$\varepsilon_\beta = 0$$

$$\varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta$$

$$\varepsilon_\gamma = 1,557$$

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

$$g_\alpha = 45,960 \text{ mm}$$

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

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

$$g_{AB} = \frac{g_\alpha - p_{et}}{2} \quad (35) \quad g_{AB} = 8,219 \text{ mm}$$

$$g_B = g_\alpha - p_{et} \quad (36) \quad g_B = 16,439 \text{ mm}$$

$$g_C = \frac{d_{b1}}{2} \cdot \tan \alpha_{wt} - \sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} + g_\alpha \quad (37) \quad g_C = 22,980 \text{ mm}$$

$$g_D = p_{et} \quad (38) \quad g_D = 29,521 \text{ mm}$$

$$g_{DE} = \frac{g_\alpha - p_{et}}{2} + p_{et} \quad (39) \quad g_{DE} = 37,741 \text{ mm}$$

$$g_E = g_\alpha \quad (40) \quad g_E = 45,960 \text{ mm}$$

$$d_{A1} = 2 \cdot \sqrt{\frac{d_{b1}^2}{4} + \left(\sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} - g_\alpha + g_A \right)^2} \quad (41) \quad d_{A1} = 189,274 \text{ mm}$$

$$d_{AB1} = 191,919 \text{ mm}$$

$$d_{B1} = 195,912 \text{ mm}$$

$$d_{C1} = 200,00 \text{ mm}$$

$$d_{D1} = 204,844 \text{ mm}$$

$$d_{DE1} = 211,920 \text{ mm}$$

$$d_{E1} = 220,000 \text{ mm}$$

$$d_{A2} = 2 \cdot \sqrt{\frac{d_{b2}^2}{4} + \left(\sqrt{\frac{d_{a2}^2}{4} - \frac{d_{b2}^2}{4}} - g_A \right)^2} \quad (42) \quad d_{A2} = 220,000 \text{ mm}$$

$$d_{AB2} = 211,920 \text{ mm}$$

$$d_{B2} = 204,844 \text{ mm}$$

$$d_{C2} = 200,000 \text{ mm}$$

$$d_{D2} = 195,912 \text{ mm}$$

$$d_{DE2} = 191,919 \text{ mm}$$

$$d_{E2} = 189,274 \text{ mm}$$

Normal radius of relative curvature:

$$\rho_{n,A} = \frac{\rho_{t,A}}{\cos \beta_b} \quad (45) \quad \rho_{n,A} = 9,381 \text{ mm}$$

$$\rho_{n,AB} = 13,916 \text{ mm}$$

$$\rho_{n,B} = 16,475 \text{ mm}$$

$$\rho_{n,C} = 17,101 \text{ mm}$$

$$\rho_{n,D} = 16,475 \text{ mm}$$

$$\rho_{n,DE} = 13,916 \text{ mm}$$

$$\rho_{n,E} = 9,381 \text{ mm}$$

4.2.2.2 Calculation of material data

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

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

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

4.2.2.3 Calculation of operating conditions

Loading:

$$P = 2 \cdot \pi \cdot \frac{n_1}{60} \cdot \frac{T_1}{1000} \quad (85) \quad P = 251 \text{ kW}$$

$$F_t = 2000 \cdot \frac{T_1}{d_1} \quad F_t = 24\,000 \text{ N}$$

$$F_{bt} = 2000 \cdot \frac{T_1}{d_{b1}} \quad F_{bt} = 25\,540 \text{ N}$$

Local load sharing factor:

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

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

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

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

Elasticity factor:

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

Local Hertzian contact stress:

$$p_{H,A,B} = Z_E \cdot \sqrt{\frac{F_t \cdot X_A}{b \cdot \rho_{n,A} \cdot \cos \alpha_t \cdot \cos \beta_b}} \quad (25) \quad p_{H,A,B} = 1\,476 \text{ N/mm}^2$$

$$p_{H,AB,B} = 1\,485 \text{ N/mm}^2 \quad p_{H,B,B} = 1\,930 \text{ N/mm}^2 \quad p_{H,C,B} = 1\,894 \text{ N/mm}^2$$

$$p_{H,D,B} = 1\,930 \text{ N/mm}^2 \quad p_{H,DE,B} = 1\,485 \text{ N/mm}^2 \quad p_{H,E,B} = 1\,476 \text{ N/mm}^2$$

$$p_{dyn,A,B} = p_{H,A,B} \cdot \sqrt{K_A \cdot K_v \cdot K_{H\alpha} \cdot K_{H\beta}} \quad (24) \quad p_{dyn,A,B} = 1\,541 \text{ N/mm}^2$$

$$p_{dyn,AB,B} = 1\,550 \text{ N/mm}^2 \quad p_{dyn,B,B} = 2\,014 \text{ N/mm}^2 \quad p_{dyn,C,B} = 1\,977 \text{ N/mm}^2$$

$$p_{dyn,D,B} = 2\,014 \text{ N/mm}^2 \quad p_{dyn,DE,B} = 1\,550 \text{ N/mm}^2 \quad p_{dyn,E,B} = 1\,541 \text{ N/mm}^2$$

Velocity:

$$v_{g,A} = v_{r1,A} - v_{r2,A} \quad (81) \quad v_{g,A} = -4,813 \text{ m/s}$$

$$v_{g,AB} = -3,091 \text{ m/s} \quad v_{g,B} = -1,370 \text{ m/s} \quad v_{g,C} = 0 \text{ m/s}$$

$$v_{g,D} = 1,370 \text{ m/s} \quad v_{g,DE} = 3,091 \text{ m/s} \quad v_{g,E} = 4,813 \text{ m/s}$$

$$v_{\Sigma,A} = v_{r1,A} + v_{r2,A} \quad (13) \quad v_{\Sigma,A} = 7,163 \text{ m/s}$$

$$v_{\Sigma,AB} = 7,163 \text{ m/s}$$

$$v_{\Sigma,B} = 7,163 \text{ m/s}$$

$$v_{\Sigma,C} = 7,163 \text{ m/s}$$

$$v_{\Sigma,D} = 7,163 \text{ m/s}$$

$$v_{\Sigma,DE} = 7,163 \text{ m/s}$$

$$v_{\Sigma,E} = 7,163 \text{ m/s}$$

Effective arithmetic mean roughness value:

$$Ra = 0,5 \cdot (Ra_1 + Ra_2) \quad (3) \quad Ra = 0,80 \text{ } \mu\text{m}$$

4.2.2.4 Calculation of lubricant data

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

$$\alpha_{38} = 2,657 \cdot 10^{-8} \cdot \eta_{38}^{0,1348} \quad (9) \quad \alpha_{38} = 2,05 \cdot 10^{-8} \text{ m}^2/\text{N}$$

$X_S = 1,2$ for injection lubrication

4.2.2.5 Calculation of the material parameter

Mean coefficient of friction:

$$X_R = 2,2 \cdot \left(\frac{Ra}{\rho_{n,C}} \right)^{0,25} \quad (87) \quad X_R = 1,023$$

$$K_{B\gamma} = 1,0 \text{ for } \varepsilon_\gamma < 2 \quad (88)$$

$$\mu_m = 0,045 \cdot \left(\frac{K_A \cdot K_v \cdot K_{H\alpha} \cdot K_{H\beta} \cdot F_{bt} \cdot K_{B\gamma}}{b \cdot v_{\Sigma,C} \cdot \rho_{n,C}} \right)^{0,2} \cdot (10^3 \cdot \eta_{\theta_{oil}})^{-0,05} \cdot X_R \cdot X_L \quad (86) \quad \mu_m = 0,067$$

Bulk temperature:

$$H_v = \left(\varepsilon_1^2 + \varepsilon_2^2 + 1 - \varepsilon_\alpha \right) \cdot \left(\frac{1}{z_1} + \frac{1}{z_2} \right) \cdot \frac{\pi}{\cos \beta_b} \text{ for } \varepsilon_\alpha < 2 \quad (91) \quad H_v = 0,206$$

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

$$X_{Ca} = 1,0 \text{ for no adequate profile modification (method B)} \quad (101)$$

$$\theta_M = \theta_{oil} + 7\,400 \cdot \left(\frac{P \cdot \mu_m \cdot H_v}{a \cdot b} \right)^{0,72} \cdot \frac{X_s}{1,2 \cdot X_{Ca}} \quad (84) \quad \theta_M = 126,6 \text{ } ^\circ\text{C}$$

Material parameter:

$$G_M = 10^6 \cdot \alpha_{\theta_M} \cdot E_r \quad (5) \quad G_M = 2\,936,2$$

4.2.2.6 Calculation of the velocity parameter

$$U_A = \eta_{\theta_M} \cdot \frac{v_{\Sigma,A}}{2000 \cdot E_r \cdot \rho_{n,A}} \quad (12) \quad U_A = 1,087 \cdot 10^{-11}$$

$$\begin{array}{lll}
 U_{AB} = 7,325 \cdot 10^{-12} & U_B = 6,187 \cdot 10^{-12} & U_C = 5,961 \cdot 10^{-12} \\
 U_D = 6,187 \cdot 10^{-12} & U_{DE} = 7,325 \cdot 10^{-12} & U_E = 1,087 \cdot 10^{-11}
 \end{array}$$

4.2.2.7 Calculation of the load parameter

$$W_A = \frac{2 \cdot \pi \cdot p_{dyn,A}^2}{E_r^2} \quad (22) \quad W_A = 2,913 \cdot 10^{-4}$$

$$\begin{array}{lll}
 W_{AB} = 2,946 \cdot 10^{-4} & W_B = 4,976 \cdot 10^{-4} & W_C = 4,794 \cdot 10^{-4} \\
 W_D = 4,976 \cdot 10^{-4} & W_{DE} = 2,946 \cdot 10^{-4} & W_E = 2,913 \cdot 10^{-4}
 \end{array}$$

4.2.2.8 Calculation of the sliding parameter

Local flash temperature:

$$\theta_{fl,A} = \frac{\sqrt{\pi}}{2} \cdot \frac{10^6 \cdot \mu_m \cdot p_{dyn,A} \cdot |v_{g,A}|}{B_{M1} \sqrt{v_{r1,A}} + B_{M2} \sqrt{v_{r2,A}}} \cdot \sqrt{8 \cdot \rho_{n,A} \cdot \frac{p_{dyn,A}}{1000 \cdot E_r}} \quad (80) \quad \theta_{fl,A} = 225,7 \text{ } ^\circ\text{C}$$

$$\begin{array}{lll}
 \theta_{fl,AB} = 170,3 \text{ } ^\circ\text{C} & \theta_{fl,B} = 119,2 \text{ } ^\circ\text{C} & \theta_{fl,C} = 0 \text{ } ^\circ\text{C} \\
 \theta_{fl,D} = 119,2 \text{ } ^\circ\text{C} & \theta_{fl,DE} = 170,3 \text{ } ^\circ\text{C} & \theta_{fl,E} = 225,7 \text{ } ^\circ\text{C}
 \end{array}$$

Local contact temperature as sum of bulk and local flash temperature:

$$\begin{array}{lll}
 \theta_{B,A} = \theta_M + \theta_{fl,A} & (79) & \theta_{B,A} = 352,3 \text{ } ^\circ\text{C} \\
 \theta_{B,AB} = 296,9 \text{ } ^\circ\text{C} & \theta_{B,B} = 245,8 \text{ } ^\circ\text{C} & \theta_{B,C} = 126,6 \text{ } ^\circ\text{C} \\
 \theta_{B,D} = 245,8 \text{ } ^\circ\text{C} & \theta_{B,DE} = 296,9 \text{ } ^\circ\text{C} & \theta_{B,E} = 352,3 \text{ } ^\circ\text{C}
 \end{array}$$

Local sliding parameter:

$$S_{GF,A} = \frac{\alpha_{\theta B,A} \cdot \eta_{\theta B,A}}{\alpha_{\theta M} \cdot \eta_{\theta M}} \quad (27) \quad S_{GF,A} = 0,024$$

$$\begin{array}{lll}
 S_{GF,AB} = 0,049 & S_{GF,B} = 0,102 & S_{GF,C} = 1,000 \\
 S_{GF,D} = 0,102 & S_{GF,DE} = 0,049 & S_{GF,E} = 0,024
 \end{array}$$

4.2.2.9 Calculation of the lubricant film thickness

$$h_A = 1600 \cdot \rho_{n,A} \cdot G_M^{0,6} \cdot U_A^{0,7} \cdot W_A^{-0,13} \cdot S_{GF,A}^{0,22} \quad (4) \quad h_A = 0,048 \text{ } \mu\text{m}$$

$$\begin{array}{lll}
 h_{AB} = 0,064 \text{ } \mu\text{m} & h_B = 0,074 \text{ } \mu\text{m} & h_C = 0,124 \text{ } \mu\text{m} \\
 h_D = 0,074 \text{ } \mu\text{m} & h_{DE} = 0,064 \text{ } \mu\text{m} & h_E = 0,048 \text{ } \mu\text{m}
 \end{array}$$

4.2.2.10 Calculation of the specific lubricant film thickness

$$\lambda_{GF,A} = \frac{h_A}{Ra} \quad (2) \quad \lambda_{GF,A} = 0,060$$

$$\lambda_{GF,AB} = 0,080 \quad \lambda_{GF,B} = 0,092 \quad \lambda_{GF,C} = 0,155$$

$$\lambda_{GF,D} = 0,092 \quad \lambda_{GF,DE} = 0,080 \quad \lambda_{GF,E} = 0,060$$

$$\lambda_{GF,min} = \lambda_{GF,A} \quad \lambda_{GF,min} = 0,060$$

4.2.2.11 Calculation of the micropitting safety factor

$$S_\lambda = \frac{\lambda_{GF,min}}{\lambda_{GFP}} \quad (1) \quad S_\lambda = 0,353$$

The final results for the calculation of the safety factor against micropitting, S_λ , for example 2 are shown in [Table 9](#).

Table 9 — Results of calculation according to method B — Example 2

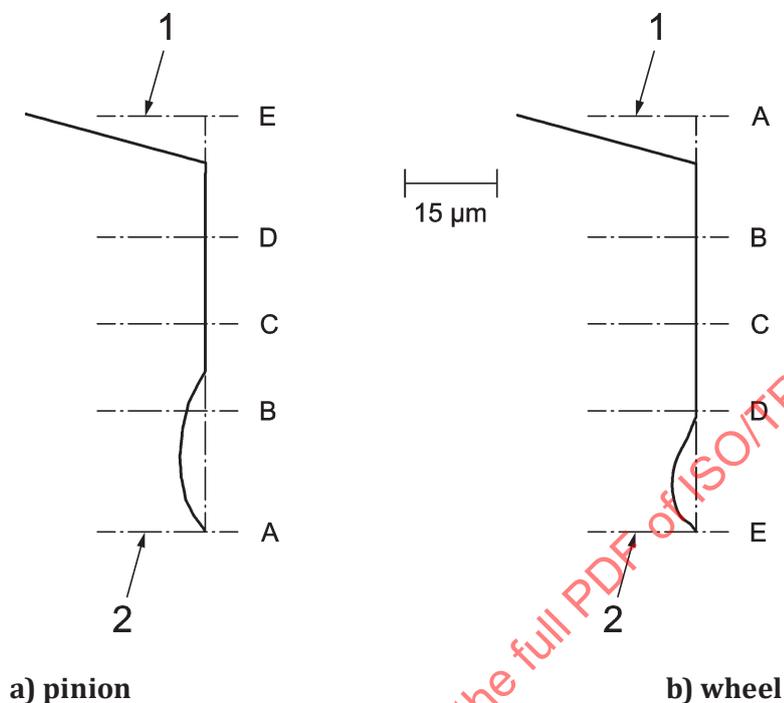
Point	A	AB	B	C	D	DE	E
$\lambda_{GF,Y}$	0,060	0,080	0,092	0,155	0,092	0,080	0,060
$\lambda_{GF,min}$	0,060						
λ_{GFP}	0,171						
S_λ	0,353						

NOTE With reference to ISO 15144-1, 5.4 for θ_{oilRef} the oil temperature, at which the test was performed, has to be used. Micropitting load capacity is significantly influenced by additives, often more than by the viscosity. As the effectiveness of additives depends significantly on temperature, it is recommended to test the oil at the temperature used in the application.

Normally, the FZG-FVA micropitting test^[1] is executed at 90 °C oil temperature. The data from oil providers should contain together with the failure load stage SKS also the test temperature.

4.3 Example 3 — Helical gear

The result of this example is confirmed by experimental investigations. The gears were obviously micropitted and had profile deviations of approximately 10 μm (pinion) and 5 μm (wheel). [Figure 3](#) shows a diagram of the observed location and severity of micropitting for pinion and wheel of example 3.



Key

- 1 tip
- 2 root

Figure 3 — Diagram of schematic profile deviations of pinion and wheel for example 3

NOTE For the calculation according to method B, no modifications were considered.

4.3.1 Input data

Table 10 — Input data for Example 3

	Symbol	Description	Unit	Example 3	
				pinion	wheel
				comb.	
Geometry	z	number of teeth	-	33	34
	-	driving gear	-	X	
	m_n	normal module	°	4,5	
	α_n	normal pressure angle	°	20	
	β	helix angle (right-hand on pinion)	mm	19,578	
	b	face width	°	44	
	a	centre distance	°	160	
	x	addendum modification factor	mm	0,0	0,0
	d_a	tip diameter of pinion	mm	166,61	171,39
	-	tooth flank modifications ^a	-	linear tip relief $C_{a1} = 50 \mu\text{m}$, $d_{\text{End}1} = 162,72 \text{ mm}$ $C_{a2} = 50 \mu\text{m}$, $d_{\text{End}2} = 162,52 \text{ mm}$	
	Q	gear quality	-	4	4
R_a	arithmetic mean roughness value	μm	0,45	0,45	
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	-	1,05	
	$K_{H\alpha}$	transverse load factor	-	1,0	
	$K_{H\beta}$	face load factor	-	1,10	
Load	T_1	nominal torque at the pinion	Nm	4 000	
	n_1	rotation speed of the pinion	min ⁻¹	3 000	

^a Calculation according to method B: modifications assumed as not adequate; calculation according to method A: modifications recognized during calculation of pressure distribution.

Table 10 (continued)

	Symbol	Description	Unit	Example 3	
				pinion	wheel
				comb.	
Lubricant	θ_{oil}	oil inlet temperature (injection lubrication)	° C	90	
	ν_{40}	kinematic viscosity at 40 °C	mm ² /s	76,5	
	ν_{100}	kinematic viscosity at 100 °C	mm ² /s	8,0	
	ρ_{15}	density of the lubricant at 15 °C	kg/m ³	895	
	-	oil type	-	mineral oil	
	λ_{GFP}	permissible lubricant film thickness determined from a representative bench test	-	0,112	

^a Calculation according to method B: modifications assumed as not adequate; calculation according to method A: modifications recognized during calculation of pressure distribution.

4.3.2 Calculation according to method B

4.3.2.1 Calculation of gear geometry (according to ISO 21771)

Basic values:

$$m_t = \frac{m_n}{\cos \beta}$$

$$m_t = 4,776 \text{ mm}$$

$$d_1 = z_1 \cdot m_t$$

$$d_1 = 157,612 \text{ mm}$$

$$d_2 = z_2 \cdot m_t$$

$$d_2 = 162,388 \text{ mm}$$

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

$$u = 1,03$$

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

$$\alpha_t = 21,122^\circ$$

$$d_{b1} = d_1 \cdot \cos \alpha_t$$

$$d_{b1} = 147,023 \text{ mm}$$

$$d_{b2} = d_2 \cdot \cos \alpha_t$$

$$d_{b2} = 151,479 \text{ mm}$$

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

$$d_{w1} = 157,612 \text{ mm}$$

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

$$d_{w2} = 162,388 \text{ mm}$$

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

$$\alpha_{wt} = 21,122^\circ$$

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

$$\beta_b = 18,354^\circ$$

$$p_{et} = m_t \cdot \pi \cdot \cos \alpha_t$$

$$p_{et} = 13,997 \text{ mm}$$

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

$$\varepsilon_1 = 0,771$$

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

$$\varepsilon_2 = 0,774$$

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

$$\varepsilon_\alpha = 1,545$$

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

$$\varepsilon_\beta = 1,043$$

$$\varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta$$

$$\varepsilon_\gamma = 2,588$$

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

$$g_\alpha = 21,623 \text{ mm}$$

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

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

$$g_{AB} = \frac{g_\alpha - p_{et}}{2} \quad (35) \quad g_{AB} = 3,813 \text{ mm}$$

$$g_B = g_\alpha - p_{et} \quad (36) \quad g_B = 7,626 \text{ mm}$$

$$g_C = \frac{d_{b1}}{2} \cdot \tan \alpha_{wt} - \sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} + g_\alpha \quad (37) \quad g_C = 10,832 \text{ mm}$$

$$g_D = p_{et} \quad (38) \quad g_D = 13,997 \text{ mm}$$

$$g_{DE} = \frac{g_\alpha - p_{et}}{2} + p_{et} \quad (39) \quad g_{DE} = 17,810 \text{ mm}$$

$$g_E = g_\alpha \quad (40) \quad g_E = 21,623 \text{ mm}$$

$$d_{A1} = 2 \cdot \sqrt{\frac{d_{b1}^2}{4} + \left(\sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} - g_\alpha + g_A \right)^2} \quad (41) \quad d_{A1} = 151,162 \text{ mm}$$

$$d_{AB1} = 153,115 \text{ mm}$$

$$d_{B1} = 155,417 \text{ mm}$$

$$d_{C1} = 157,612 \text{ mm}$$

$$d_{D1} = 160,002 \text{ mm} \quad d_{DE1} = 163,161 \text{ mm} \quad d_{E1} = 166,610 \text{ mm}$$

$$d_{A2} = 2 \cdot \sqrt{\frac{d_{b2}^2}{4} + \left(\sqrt{\frac{d_{a2}^2}{4} - \frac{d_{b2}^2}{4}} - g_A \right)^2} \quad (42) \quad d_{A2} = 171,390 \text{ mm}$$

$$d_{AB2} = 167,957 \text{ mm} \quad d_{B2} = 164,807 \text{ mm} \quad d_{C2} = 162,388 \text{ mm}$$

$$d_{D2} = 160,216 \text{ mm} \quad d_{DE2} = 157,897 \text{ mm} \quad d_{E2} = 155,916 \text{ mm}$$

Normal radius of relative curvature:

$$\rho_{n,A} = \frac{\rho_{t,A}}{\cos \beta_b} \quad (45) \quad \rho_{n,A} = 12,869 \text{ mm}$$

$$\rho_{n,AB} = 14,173 \text{ mm} \quad \rho_{n,B} = 14,945 \text{ mm} \quad \rho_{n,C} = 15,183 \text{ mm}$$

$$\rho_{n,D} = 15,050 \text{ mm} \quad \rho_{n,DE} = 14,403 \text{ mm} \quad \rho_{n,E} = 13,225 \text{ mm}$$

4.3.2.2 Calculation of material data

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

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

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

4.3.2.3 Calculation of operating conditions

Loading:

$$P = 2 \cdot \pi \cdot \frac{n_1}{60} \cdot \frac{T_1}{1000} \quad (85) \quad P = 1\,257 \text{ kW}$$

$$F_t = 2000 \cdot \frac{T_1}{d_1} \quad F_t = 50\,758 \text{ N}$$

$$F_{bt} = 2000 \cdot \frac{T_1}{d_{b1}} \quad F_{bt} = 54\,413 \text{ N}$$

Local load sharing factor:

NOTE Helical gears, $\varepsilon_\beta \geq 1$, unmodified profile (see ISO/TR 15144-1:2014, Figure 12).

$$X_A = \frac{1}{\varepsilon_\alpha} \cdot X_{\text{but},A} \quad (69) \quad X_A = 0,841 \quad (X_{\text{but},A} = 1,3)$$

$X_{AB} = 0,647$	$X_B = 0,647$	$X_C = 0,647$
$(X_{but,AB} = 1,0)$	$(X_{but,B} = 1,0)$	$(X_{but,C} = 1,0)$
$X_D = 0,647$	$X_{DE} = 0,647$	$X_E = 0,841$
$(X_{but,D} = 1,0)$	$(X_{but,DE} = 1,0)$	$(X_{but,E} = 1,0)$

Elasticity factor:

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

Local Hertzian contact stress:

$$p_{H,A,B} = Z_E \cdot \sqrt{\frac{F_t \cdot X_A}{b \cdot \rho_{n,A} \cdot \cos \alpha_t \cdot \cos \beta_b}} \quad (25) \quad p_{H,A,B} = 1\,752 \text{ N/mm}^2$$

$p_{H,AB,B} = 1\,464 \text{ N/mm}^2$	$p_{H,B,B} = 1\,426 \text{ N/mm}^2$	$p_{H,C,B} = 1\,415 \text{ N/mm}^2$
$p_{H,D,B} = 1\,421 \text{ N/mm}^2$	$p_{H,DE,B} = 1\,452 \text{ N/mm}^2$	$p_{H,E,B} = 1\,728 \text{ N/mm}^2$

$$p_{dyn,A,B} = p_{H,A,B} \cdot \sqrt{K_A \cdot K_v \cdot K_{H\alpha} \cdot K_{H\beta}} \quad (24) \quad p_{dyn,A,B} = 1\,883 \text{ N/mm}^2$$

$p_{dyn,AB,B} = 1\,574 \text{ N/mm}^2$	$p_{dyn,B,B} = 1\,532 \text{ N/mm}^2$	$p_{dyn,C,B} = 1\,520 \text{ N/mm}^2$
$p_{dyn,D,B} = 1\,527 \text{ N/mm}^2$	$p_{dyn,DE,B} = 1\,561 \text{ N/mm}^2$	$p_{dyn,E,B} = 1\,857 \text{ N/mm}^2$

Velocity:

$$v_{g,A} = v_{r1,A} - v_{r2,A} \quad (81) \quad v_{g,A} = -6,706 \text{ m/s}$$

$v_{g,AB} = -4,345 \text{ m/s}$	$v_{g,B} = -1,984 \text{ m/s}$	$v_{g,C} = 0 \text{ m/s}$
$v_{g,D} = 1,959 \text{ m/s}$	$v_{g,DE} = 4,320 \text{ m/s}$	$v_{g,E} = 6,681 \text{ m/s}$

$$v_{\Sigma,A} = v_{r1,A} + v_{r2,A} \quad (13) \quad v_{\Sigma,A} = 17,743 \text{ m/s}$$

$v_{\Sigma,AB} = 17,778 \text{ m/s}$	$v_{\Sigma,B} = 17,813 \text{ m/s}$	$v_{\Sigma,C} = 17,843 \text{ m/s}$
$v_{\Sigma,D} = 17,872 \text{ m/s}$	$v_{\Sigma,DE} = 17,907 \text{ m/s}$	$v_{\Sigma,E} = 17,942 \text{ m/s}$

Effective arithmetic mean roughness value:

$$Ra = 0,5 \cdot (Ra_1 + Ra_2) \quad (3) \quad Ra = 0,45 \text{ }\mu\text{m}$$

4.3.2.4 Calculation of lubricant data

$X_L = 1,0$ for mineral oil (see Table 3 in ISO/TR 15144 part 1)

$$\alpha_{38} = 2,657 \cdot 10^{-8} \cdot \eta_{38}^{0,1348} \quad (9) \quad \alpha_{38} = 1,88 \cdot 10^{-8} \text{ m}^2/\text{N}$$

$X_S = 1,2$ for injection lubrication

4.3.2.5 Calculation of the material parameter

Mean coefficient of friction:

$$X_R = 2,2 \cdot \left(\frac{Ra}{\rho_{n,C}} \right)^{0,25} \quad (87) \quad X_R = 0,913$$

$$K_{B\gamma} = 1,238 \text{ for } 2 < \varepsilon_\gamma < 3,5 \quad (89)$$

$$\mu_m = 0,045 \cdot \left(\frac{K_A \cdot K_v \cdot K_{H\alpha} \cdot K_{H\beta} \cdot F_{bt} \cdot K_{B\gamma}}{b \cdot v_{\Sigma,C} \cdot \rho_{n,C}} \right)^{0,2} \cdot (10^3 \cdot \eta_{\theta oil})^{-0,05} \cdot X_R \cdot X_L \quad (86) \quad \mu_m = 0,054$$

Bulk temperature:

$$H_v = (\varepsilon_1^2 + \varepsilon_2^2 + 1 - \varepsilon_\alpha) \cdot \left(\frac{1}{z_1} + \frac{1}{z_2} \right) \cdot \frac{\pi}{\cos \beta_b} \text{ for } \varepsilon_\alpha < 2 \quad (91) \quad H_v = 0,128$$

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

$$X_{Ca} = 1,0 \text{ for no adequate profile modification (method B)} \quad (101)$$

$$\theta_M = \theta_{oil} + 7\,400 \cdot \left(\frac{P \cdot \mu_m \cdot H_v}{a \cdot b} \right)^{0,72} \cdot \frac{X_S}{1,2 \cdot X_{Ca}} \quad (84) \quad \theta_M = 149,3 \text{ }^\circ\text{C}$$

Material parameter:

$$G_M = 10^6 \cdot \alpha_{\theta M} \cdot E_r \quad (5) \quad G_M = 238,5$$

4.3.2.6 Calculation of the velocity parameter

$$U_A = \eta_{\theta M} \cdot \frac{V_{\Sigma,A}}{2000 \cdot E_r \cdot \rho_{n,A}} \quad (12) \quad U_A = 7,431 \cdot 10^{-12}$$

$$U_{AB} = 6,761 \cdot 10^{-12} \quad U_B = 6,424 \cdot 10^{-12} \quad U_C = 6,334 \cdot 10^{-12}$$

$$U_D = 6,400 \cdot 10^{-12} \quad U_{DE} = 6,701 \cdot 10^{-12} \quad U_E = 7,312 \cdot 10^{-12}$$

4.3.2.7 Calculation of the load parameter

$$W_A = \frac{2 \cdot \pi \cdot p_{dyn,A}^2}{E_r^2} \quad (22) \quad W_A = 4,347 \cdot 10^{-4}$$

$$W_{AB} = 3,036 \cdot 10^{-4} \quad W_B = 2,879 \cdot 10^{-4} \quad W_C = 2,834 \cdot 10^{-4}$$

$$W_D = 2,859 \cdot 10^{-4} \quad W_{DE} = 2,988 \cdot 10^{-4} \quad W_E = 4,230 \cdot 10^{-4}$$

4.3.2.8 Calculation of the sliding parameter

Local flash temperature:

$$\theta_{fl,A} = \frac{\sqrt{\pi}}{2} \cdot \frac{10^6 \cdot \mu_m \cdot p_{dyn,A} \cdot |v_{g,A}|}{B_{M1} \sqrt{v_{r1,A}} + B_{M2} \sqrt{v_{r2,A}}} \cdot \sqrt{8 \cdot \rho_{n,A} \cdot \frac{p_{dyn,A}}{1000 \cdot E_r}} \quad (80) \quad \theta_{fl,A} = 241,7 \text{ } ^\circ\text{C}$$

$$\theta_{fl,AB} = 124,0 \text{ } ^\circ\text{C}$$

$$\theta_{fl,B} = 55,5 \text{ } ^\circ\text{C}$$

$$\theta_{fl,C} = 0 \text{ } ^\circ\text{C}$$

$$\theta_{fl,D} = 54,6 \text{ } ^\circ\text{C}$$

$$\theta_{fl,DE} = 122,4 \text{ } ^\circ\text{C}$$

$$\theta_{fl,E} = 237,7 \text{ } ^\circ\text{C}$$

Local contact temperature as sum of bulk and local flash temperature:

$$\theta_{B,A} = \theta_M + \theta_{fl,A} \quad (79) \quad \theta_{B,A} = 391,0 \text{ } ^\circ\text{C}$$

$$\theta_{B,AB} = 273,4 \text{ } ^\circ\text{C}$$

$$\theta_{B,B} = 204,8 \text{ } ^\circ\text{C}$$

$$\theta_{B,C} = 149,3 \text{ } ^\circ\text{C}$$

$$\theta_{B,D} = 203,9 \text{ } ^\circ\text{C}$$

$$\theta_{B,DE} = 271,7 \text{ } ^\circ\text{C}$$

$$\theta_{B,E} = 387,0 \text{ } ^\circ\text{C}$$

Local sliding parameter:

$$S_{GF,A} = \frac{\alpha_{\theta B,A} \cdot \eta_{\theta B,A}}{\alpha_{\theta M} \cdot \eta_{\theta M}} \quad (27) \quad S_{GF,A} = 0,030$$

$$S_{GF,AB} = 0,135$$

$$S_{GF,B} = 0,361$$

$$S_{GF,C} = 1,000$$

$$S_{GF,D} = 0,366$$

$$S_{GF,DE} = 0,138$$

$$S_{GF,E} = 0,031$$

4.3.2.9 Calculation of the lubricant film thickness

$$h_A = 1600 \cdot \rho_{n,A} \cdot G_M^{0,6} \cdot U_A^{0,7} \cdot W_A^{-0,13} \cdot S_{GF,A}^{0,22} \quad (4) \quad h_A = 0,045 \text{ } \mu\text{m}$$

$$h_{AB} = 0,067 \text{ } \mu\text{m}$$

$$h_B = 0,086 \text{ } \mu\text{m}$$

$$h_C = 0,108 \text{ } \mu\text{m}$$

$$h_D = 0,087 \text{ } \mu\text{m}$$

$$h_{DE} = 0,069 \text{ } \mu\text{m}$$

$$h_E = 0,046 \text{ } \mu\text{m}$$

4.3.2.10 Calculation of the specific lubricant film thickness

$$\lambda_{GF,A} = \frac{h_A}{Ra} \quad (2) \quad \lambda_{GF,A} = 0,099$$

$$\lambda_{GF,AB} = 0,150$$

$$\lambda_{GF,B} = 0,191$$

$$\lambda_{GF,C} = 0,241$$

$$\lambda_{GF,D} = 0,192$$

$$\lambda_{GF,DE} = 0,152$$

$$\lambda_{GF,E} = 0,103$$

$$\lambda_{GF,min} = \lambda_{GF,A}$$

$$\lambda_{GF,min} = 0,099$$

4.3.2.11 Calculation of the micropitting safety factor

$$S_\lambda = \frac{\lambda_{GF,min}}{\lambda_{GFP}} \quad (1) \quad S_\lambda = 0,884$$

The final results for the calculation of the safety factor against micropitting, S_λ , for example 3 are shown in [Table 11](#).

Table 11 — Results of calculation according to method B — Example 3

Point	A	AB	B	C	D	DE	E
$\lambda_{GF,Y}$	0,099	0,150	0,191	0,241	0,192	0,152	0,103
$\lambda_{GF,min}$	0,099						
λ_{GFP}	0,112						
S_λ	0,884						

4.3.3 Calculation according to method A

The calculation of example 3 according to method A was carried out by a 3D-calculation programme. Calculated results during method A will vary depending on the method of determining load distribution. The load distribution, on which the following calculation according to method A is based, is shown in [Table 12](#). The maximum values are printed in bold.

Table 12 — Matrix of pressure distribution — $p_{H,Y,A}$ in N/mm²

	Width in mm			
	0,0	15,5	28,5	44,0
A	1 205	768	742	384
AB	1 572	1 456	1 457	1 273
B	1 568	1 560	1 550	1 589
C	1 518	1 510	1 530	1 582
D	1 516	1 529	1 574	1 621
DE	1 192	1 423	1 454	1 623
E	250	655	765	1 513

The resulting matrix of specific lubricant film thickness according to method A is shown in [Table 13](#). The minimum value is printed in bold.

Table 13 — Matrix of resulting specific lubricant film thickness, $\lambda_{GF,Y}$

	Width in mm			
	0,0	15,5	28,5	44,0
A	0,198	0,274	0,280	0,391
AB	0,191	0,203	0,203	0,225
B	0,244	0,245	0,246	0,242
C	0,323	0,324	0,323	0,320
D	0,251	0,250	0,245	0,241
DE	0,238	0,209	0,205	0,188
E	0,467	0,306	0,279	0,163

For the calculation of the micropitting safety factor according to method A, the minimum value of the matrix of resulting specific lubricant film thickness, shown in [Table 13](#), was used.

$$S_{\lambda} = \frac{\lambda_{GF,\min}}{\lambda_{GFP}} \qquad S_{\lambda} = 1,124$$

NOTE The difference in safety factor calculated between methods A and B in the above example 3 results from the simplified analysis of method B, in relation to the account for profile modification. In example 3, the amount of tip relief is not calculated as being optimum for the specified load; therefore, the calculations for method B are based on contact conditions with no consideration for tip relief.

4.4 Example 4 — Speed increaser

The result of this example is confirmed by experimental investigations. The gears were obviously micropitted and had profile deviations of approximately 12 μm (pinion) and 3 μm (wheel). [Figure 3](#) shows a diagram of the observed location and severity of micropitting for pinion and wheel of example 4.

NOTE It has to be considered that in example 4, the wheel is the driving gear. The beginning of tooth contact in this example is at the root of the wheel, point E.

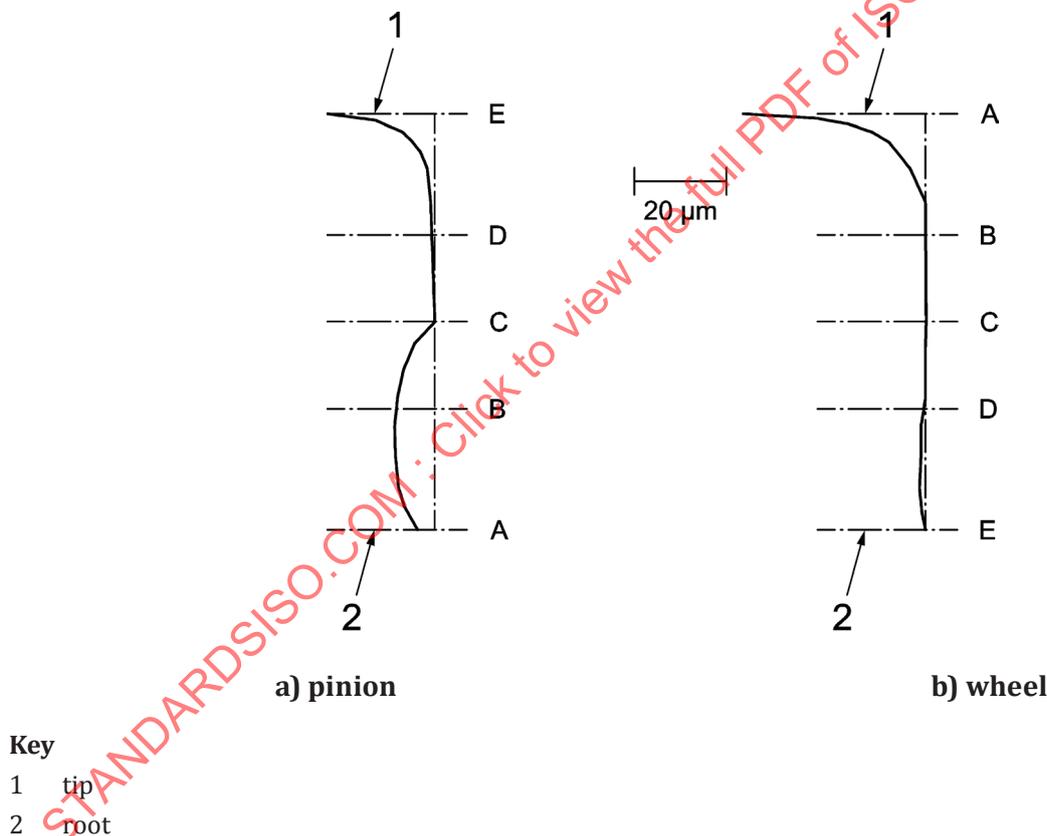


Figure 4 — Diagram of schematic profile deviations of pinion and wheel for example 4

NOTE For the calculation according to method B, no modifications were considered.