TECHNICAL REPORT

ISO/TR 6336-31

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Calculation of load capacity of spur and helical gears —

Part 31: Calculation examples of micropitting load capacity

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

Partie 31: Exemples de calcul de la capacité de charge aux 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 of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

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

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This document cancels and replaces ISO/TR 15144-2:2014.

Introduction

The ISO 6336 series consists of International Standards, Technical Specifications (TS) and Technical Reports (TR) under the general title *Calculation of load capacity of spur and helical gears* (see Table 1).

— International Standards contain calculation methods that are based on widely accepted practices and have been validated.

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

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

The procedures specified in ISO 6336-1 to ISO 6336-19 cover fatigue analyses for gear rating. The procedures described in ISO 6336-20 to ISO 6336-29 are predominantly related to the tribological behaviour of the lubricated flank surface contact. ISO 6336-30 to ISO 6336-39 include example calculations. The ISO 6336 series allows the addition of new parts under appropriate numbers to reflect knowledge gained in the future.

Requesting standardized calculations according to ISO 6336 without referring to specific parts requires the use of only those parts that are currently designated as International Standards (see Table 1 for listing). When requesting further calculations, the relevant part or parts of ISO 6336 need to be specified. Use of a Technical Specification as acceptance criteria for a specific design needs to be agreed in advance between manufacturer and purchaser.

Table 1 — Overview of ISO 6336

Calculation of load capacity of spur and helical gears	International Standard	Technical Specification	Technical Report
Part 1: Basic principles, introduction and general influence factors	X		
Part 2: Calculation of surface durability (pitting)	X		
Part 3: Calculation of tooth bending strength	X		
Part 4: Calculation of tooth flank fracture load capacity		X	
Part 5: Strength and quality of materials	X		
Part 6: Calculation of service life under variable load	X		
Part 20: Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) — Flash temperature method (Replaces ISO/TR 13989-1)		X	
Part 21: Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) — Integral temperature method (Replaces ISO/TR 13989-2)		X	
Part 22: Calculation of micropitting load capacity (Replaces ISO/TR 15144-1)		X	
Part 30: Calculation examples for the application of ISO 6336-1, 2, 3, 5			X
Part 31: Calculation examples of micropitting load capacity (Replaces: ISO/TR 15144-2)			X
At the time of publication of this document, some of the parts listed here were under development. Consult the ISO website.			

This document provides worked examples for the application of the calculation procedures defined in ISO/TS 6336-22. 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/TS 6336-22. No additional calculations are presented in this document that are outside of ISO/TS 6336-22.

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/TS 6336-22. Several of the worked examples are presented with the calculation procedures performed in accordance with the application of both methods A and B.

Calculation of load capacity of spur and helical gears —

Part 31:
Calculation examples of micropitting load capacity

1 Scope

The example calculations presented here are provided for guidance on the application of the technical specification ISO/TS 6336-22 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/TS 6336-22.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

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

ISO/TS 6336-22:2018, *Calculation of load capacity of spur and helical gears — Part 22: Calculation of micropitting load capacity*

3 Terms and definitions

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

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

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

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

4 Symbols and units

The symbols used in this document are given in Table 2. 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 2 — Symbols and units

Symbol	Description	Unit
a	centre distance	mm
A	ISO tolerance class according ISO 1328-1:2013	—
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 capacity of pinion	J/(kg·K)
c_{M2}	specific heat capacity 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_{BY}	helical load factor	—
$K_{H\alpha}$	transverse load factor	—
$K_{H\beta}$	face load factor	—
K_v	dynamic factor	—
K_γ	mesh load 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	—

Table 2 *(continued)*

Symbol	Description	Unit
S_{λ}	safety factor against micropitting	—
$S_{\lambda,\text{min}}$	minimum required safety factor against micropitting	—
T_1	nominal torque at the pinion	Nm
U_{Y}	local velocity parameter	—
u	gear ratio	—
$v_{\text{g,Y}}$	local sliding velocity	m/s
$v_{\text{r1,Y}}$	local tangential velocity on pinion	m/s
$v_{\text{r2,Y}}$	local tangential velocity on wheel	m/s
$v_{\Sigma,\text{C}}$	sum of tangential velocities at pitch point	m/s
$v_{\Sigma,\text{Y}}$	sum of tangential velocities at point Y	m/s
W_{W}	material factor	—
W_{Y}	local load parameter	—
$X_{\text{but,Y}}$	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	$(\text{N/mm}^2)^{0,5}$
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	°
$\alpha_{\theta\text{B,Y}}$	pressure-viscosity coefficient at local contact temperature	m^2/N
$\alpha_{\theta\text{M}}$	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	—
$\varepsilon_{\alpha\text{n}}$	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	—
$\eta_{\theta\text{B,Y}}$	dynamic viscosity at local contact temperature	N·s/m^2
$\eta_{\theta\text{M}}$	dynamic viscosity at bulk temperature	N·s/m^2
$\eta_{\theta\text{oil}}$	dynamic viscosity at oil inlet/sump temperature	N·s/m^2
η_{38}	dynamic viscosity at 38 °C	N·s/m^2
$\theta_{\text{B,Y}}$	local contact temperature	°C
$\theta_{\text{fl,Y}}$	local flash temperature	°C
θ_{M}	bulk temperature	°C
θ_{oil}	oil inlet/sump temperature	°C
$\lambda_{\text{GF,min}}$	minimum specific lubricant film thickness in the contact area	—
$\lambda_{\text{GF,Y}}$	local specific lubricant film thickness	—

Table 2 *(continued)*

Symbol	Description	Unit
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
Subscript 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).	

5 Example calculation

5.1 General

This clause 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/TS 6336-22 are given.

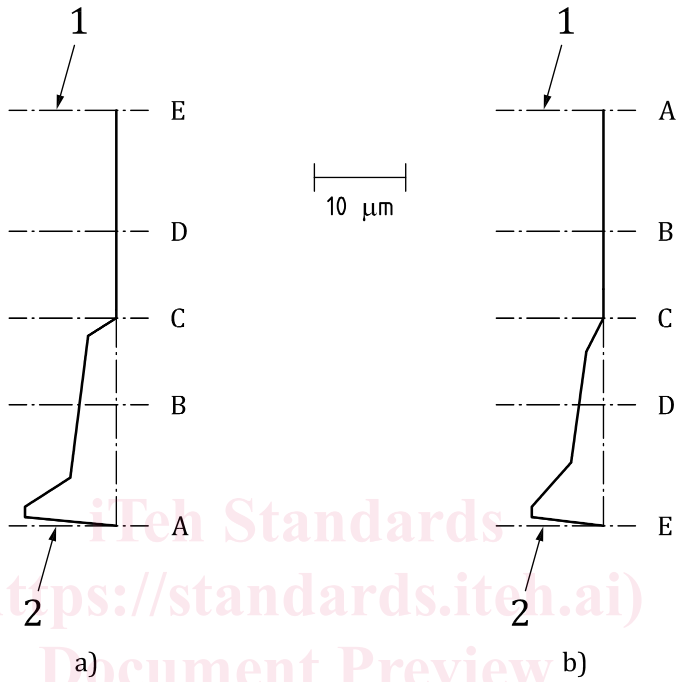
The examples calculate the safety factor, S_λ of a specific gear set when compared to an allowable λ_{GFP} value. For the examples 1, 2, and 4, the permissible specific oil film thickness, λ_{GFP}, was determined from the test result of the lubricant in the FZG-FVA micropitting test[1]. For these calculations, 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.

5.2 Example 1 Spur gear

5.2.1 General

The result of this example is confirmed by experimental investigations. The gears were obviously micropitted and had profile deviations of approximately 8 µm 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

5.2.2 Input data

Table 3 — 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

Table 3 *(continued)*

	Symbol	Description	Unit	Example 1	
				Pinion	Wheel
				Comb.	
	d_a	tip diameter	mm	221,4	221,4
	—	tooth flank modifications	—	no modifications	
	A	ISO tolerance class	—	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 capacity	J/(kg·K)	440	440
	ρ_M	density	kg/m^3	7 800	7 800
	W_w	material factor according to ISO/TS 6336-22:2018, Table A.1 (for matching case carburized/ case carburized)	—	1,0	
Application	K_A	application factor	—	1,0	
	K_v	dynamic factor	—	1,15	
	K_γ	mesh load factor	—	1,0	
	$K_{H\alpha}$	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 5.2.5 for calculation)	—	0,211	

5.2.3 Calculation according to method B

5.2.3.1 Calculation of gear geometry (according to ISO 21771)

Basic values:

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

$$d_1 = z_1 \cdot m_t \qquad d_1 = 196{,}74 \text{ mm}$$

$$d_2 = z_2 \cdot m_t \qquad d_2 = 196{,}74 \text{ mm}$$

$$u = \frac{z_2}{z_1}$$ $u = 1{,}00$

$$\alpha_t = \arctan\left(\frac{\tan\alpha_n}{\cos\beta}\right)$$ $\alpha_t = 20{,}000°$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$g_A = 0 \text{ mm} \quad (32)$$ $g_A = 0 \text{ mm}$

$$g_{AB} = \frac{g_\alpha - p_{et}}{2} \quad (33)$$ $g_{AB} = 6{,}626 \text{ mm}$

$$g_B = g_\alpha - p_{et} \quad (34)$$ $g_B = 13{,}253 \text{ mm}$

$$g_C = \frac{d_{b1}}{2} \cdot \tan\alpha_{wt} - \sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} + g_\alpha \quad (35) \quad g_C = 22{,}760 \text{ mm}$$

$$g_D = p_{et} \quad (36) \quad g_D = 32{,}267 \text{ mm}$$

$$g_{DE} = \frac{g_\alpha - p_{et}}{2} + p_{et} \quad (37) \quad g_{DE} = 28{,}893 \text{ mm}$$

$$g_E = g_\alpha \quad (38) \quad g_E = 45{,}519 \text{ mm}$$

$$d_{A1} = 2 \cdot \sqrt{\frac{d_{b1}^2}{4} + \left(\sqrt{\frac{d_{a1}^2}{4} - \frac{d_{b1}^2}{4}} - g_\alpha + g_A\right)^2} \quad (39) \quad d_{A1} = 187{,}419 \text{ mm}$$

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

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

$$d_{A2} = 2 \cdot \sqrt{\frac{d_{b2}^2}{4} + \left(\sqrt{\frac{d_{a2}^2}{4} - \frac{d_{b2}^2}{4}} - g_A\right)^2} \quad (40) \quad d_{A2} = 221{,}400 \text{ mm}$$

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

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

Normal radius of relative curvature:

$$\rho_{n,A} = \frac{\rho_{t,A}}{\cos\beta_b} \quad (43) \quad \rho_{n,A} = 12{,}285 \text{ mm}$$

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

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

5.2.3.2 Calculation of material data

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

$$B_{M1} = \sqrt{\lambda_{M1} \cdot \rho_{M1} \cdot c_{M1}} \quad (81) \quad B_{M1} = 12\,427{,}4 \text{ N}/\left(\text{ms}^{0{,}5}\text{K}\right)$$

$$B_{M2} = \sqrt{\lambda_{M2} \cdot \rho_{M2} \cdot c_{M2}} \quad (82) \quad B_{M2} = 12\,427{,}4 \text{ N}/\left(\text{ms}^{0{,}5}\text{K}\right)$$