TECHNICAL SPECIFICATION

ISO/TS 6336-22

First edition
2018-08

Calculation of load capacity of spur and helical gears —

Part 22:
Calculation of micropitting load capacity

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

Partie 22: Calcul de la capacité de charge aux micropiqûres

Reference number
ISO/TS 6336-22:2018(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation 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 first edition of ISO/TS 6336-22 cancels and replaces ISO/TR 15144-1:2014.

A list of all parts in the ISO 6336 series can be found on the ISO website. See also the Introduction for an overview.

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 parts 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 principles for the calculation of the micropitting load capacity of cylindrical involute spur and helical gears with external teeth.

The basis for the calculation of the micropitting load capacity of a gear set is the model of the minimum operating specific lubricant film thickness in the contact zone. Many parameters can influence the occurrence of micropitting. These include surface topography, contact stress level, and lubricant chemistry. Whilst these parameters are known to affect the performance of micropitting for a gear set, the subject area remains a topic of research and, as such, the science has not yet developed such that all aspects of these specific parameters are fully included in the calculation methods. Furthermore, the correct application of tip and root relief (involute modification) has been found to greatly influence micropitting; the suitable values should therefore be applied. Surface finish is another crucial parameter. At present, *R*a is used but other aspects such as *R*z or skewness have been observed to have significant effects which can be reflected in the finishing process applied.

Although the calculation of specific lubricant film thickness (which is also referred to in literature as "film thickness ratio" or "lambda ratio") does not provide a direct method for assessing micropitting load capacity, it can serve as an evaluation criterion when applied as part of a suitable comparative procedure based on known gear performance.

Calculation of load capacity of spur and helical gears —

Part 22: Calculation of micropitting load capacity

1 Scope

This document describes a procedure for the calculation of the micropitting load capacity of cylindrical gears with external teeth. It has been developed on the basis of testing and observation of oil-lubricated gear transmissions with modules between 3 mm and 11 mm and pitch line velocities of 8 m/s to 60 m/s. However, the procedure is applicable to any gear pair where suitable reference data are available, providing the criteria specified below are satisfied.

The formulae specified are applicable for driving as well as for driven cylindrical gears with tooth profiles in line with the basic rack specified in ISO 53. They are also applicable for teeth conjugate to other basic racks where the virtual contact ratio ($\varepsilon_{\alpha n}$) is less than 2,5. The results are in good agreement with other methods for normal working pressure angles up to 25°, reference helix angles up to 25° and in cases where pitch line velocity is higher than 2 m/s.

This document is not applicable for the assessment of types of gear tooth surface damage other than micropitting.

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 53, *Cylindrical gears for general and heavy engineering — Standard basic rack tooth profile*

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

ISO 1328-1, *Cylindrical gears — ISO system of flank tolerance classification — Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth*

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)*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1122-1, ISO 6336-1 and ISO 6336-2 and the following 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 http://www.electropedia.org/

3.2 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 to ISO 1328-1	—
B_{M1}	thermal contact coefficient of pinion	N/(m·s^{0,5}·K)
B_{M2}	thermal contact coefficient of wheel	N/(m·s^{0,5}·K)
b	face width	mm
C	auxiliary constant	mm
C_{a1}	tip relief of pinion	µm
C_{a2}	tip relief of wheel	µm
C_{eff}	effective tip relief	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
EAP	end of active profile (for driving pinion: contact point E, for driving wheel: contact point A)	—
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	—
$K_{B\gamma}$	helical load factor	—
$K_{H\alpha}$	transverse load factor	—
$K_{H\beta}$	face load factor	—
K_v	dynamic factor	—
K_γ	mesh load factor	—

Table 2 *(continued)*

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

Table 2 *(continued)*

Symbol	Description	Unit
ε_1	addendum contact ratio of the pinion	—
ε_2	addendum contact ratio of the wheel	—
$\eta_{\theta B,Y}$	dynamic viscosity at local contact temperature	$N \cdot s/m^2$
$\eta_{\theta M}$	dynamic viscosity at bulk temperature	$N \cdot s/m^2$
$\eta_{\theta oil}$	dynamic viscosity at oil inlet/sump temperature	$N \cdot s/m^2$
η_{38}	dynamic viscosity at 38 °C	$N \cdot s/m^2$
$\theta_{B,Y}$	local contact temperature	°C
$\theta_{fl,Y}$	local flash temperature	°C
θ_M	bulk temperature	°C
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	$W/(m \cdot K)$
λ_{M2}	specific heat conductivity of wheel	$W/(m \cdot K)$
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 have to be calculated with local values)	

4 Micropitting

Micropitting is a phenomenon that occurs in Hertzian type of rolling and sliding contact that operates in mixed elastohydrodynamic or boundary lubrication regimes. Micropitting is influenced by operating conditions such as load, speed, sliding, temperature, surface topography, specific lubricant film thickness and chemical composition of the lubricant. Micropitting is more commonly observed on materials with a high surface hardness.

Micropitting is the generation of numerous surface cracks. The cracks grow at a shallow angle to the surface forming micropits. The micropits are small relative to the size of the contact zone, typically of the order 10 µm to 20 µm deep. The micropits can coalesce to produce a continuous fractured surface which appears as a dull, matte surface during unmagnified visual inspection.

Micropitting is the preferred name for this phenomenon, but it has also been referred to as grey staining, grey flecking, frosting and peeling, see ISO 10825.

Micropitting can arrest. However, if micropitting continues to progress, it can result in reduced gear tooth accuracy, increased dynamic loads and noise. If it does not arrest and continues to propagate it can develop into macropitting and other modes of gear failure.

5 Basic formulae

5.1 General

The calculation of micropitting load capacity is based on the local specific lubricant film thickness, $\lambda_{GF,Y}$, in the contact area and the permissible specific lubricant film thickness, λ_{GFP}[11]. It is assumed that micropitting can occur, when the minimum specific lubricant film thickness, $\lambda_{GF,min}$, is lower than a corresponding critical value, λ_{GFP}. Both values, $\lambda_{GF,min}$ and λ_{GFP}, shall be calculated separately for pinion and wheel in the contact area. It needs to be recognized that the determination of the minimum specific lubricant film thickness and the permissible specific lubricant film thickness shall be based on the operating parameters.

The formulae specified are applicable for driving as well as driven cylindrical gears with tooth profiles in accordance with the basic rack specified in ISO 53. They are also applicable for teeth conjugate to other basic racks where the virtual contact ratio ($\varepsilon_{\alpha n}$) is less than 2,5.

The bulk temperature is established by the thermal balance of the gear unit. There are several sources of heat in a gear unit of which the most important are tooth and bearing friction. Other sources of heat such as seals and oilflow contribute to some extent. At pitch line velocities in excess of 80 m/s, heat from the churning of oil in the mesh and windage losses can become significant and should be taken into consideration (see Method A). The heat is transferred to the environment via the housing walls by conduction, convection and radiation and for spray lubrication conditions through the oil into an external heat exchanger.

With decreasing pitch line velocities, the lubricant film thickness, h, and consequently the safety factor against micropitting, S_λ, are decreasing. In low speed applications, wear can become the dominant mechanism. This has been observed in experimental investigations with lubricant film thicknesses at the pitch point $h_C \leq 0{,}1$ µm. For such applications, experimental investigations according to Method A or Method B under representative (test) conditions should be carried out for lubricant film thicknesses similar to those at operating conditions in order to verify if micropitting still is the main mechanism.

The micropitting load capacity can be determined by comparing the minimum specific lubricant film thickness with the corresponding limiting value derived from gears in service or from specific gear testing. This comparison is expressed by the safety factor, S_λ, which shall be equal to or higher than a minimum safety factor against micropitting, $S_{\lambda,min}$.

Micropitting mainly occurs in areas of negative specific sliding. Negative specific sliding is to be found along the path of contact between point A and C on the driving gear and between point C and E on the driven gear. Considering the influences of lubricant, surface roughness, geometry of the gears and operating conditions the specific lubricant film thickness, $\lambda_{GF,Y}$, can be calculated for every point in the field of contact.

