SLOVENSKI STANDARD
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Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears -- Part 1: Flash temperature method

Calcul de la capacité de charge au grippage des engrenages cylindriques, coniques et hypoïdes -- Partie 1: Méthode de la température-éclair

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TECHNICAL REPORT

ISO/TR 13989-1

First edition
2000-03-15

Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears —

Part 1:
Flash temperature method

Calcul de la capacité de charge au grippage des engrenages cylindriques, coniques et hypoïdes —

Partie 1: Méthode de la température-éclair

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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 main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

Technical Reports are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Attention is drawn to the possibility that some of the elements of this part of ISO/TR 13989 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 13989-1, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

This document is being issued in the Technical Report (type 2) series of publications (according to subclause G.3.2.2 of Part 1 of the ISO/IEC Directives, 1995) as a "prospective standard for provisional application" in the field of scuffing load capacity of gears because there is an urgent need for guidance on how standards in this field should be used to meet an identified need. In 1975, two methods to evaluate the risk of scuffing were documented to be studied by ISO/TC 60. It was agreed that after a period of experience one method shall be selected. Since the subject is still under technical development and there is a future possibility of an agreement on an International Standard, the publication of a type 2 Technical Report was proposed.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the ISO Central Secretariat.

A review of this Technical Report (type 2) will be carried out not later than three years after its publication with the options of: extension for another three years; conversion into an International Standard; or withdrawal.

ISO/TR 13989 consists of the following parts, under the general title *Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears*:

— *Part 1: Flash temperature method*

— *Part 2: Integral temperature method*

Annexes A and B of this part of ISO 13989 are for information only.

Introduction

Since 1990 the flash temperature method, presented in this part of ISO/TR 13989, was enriched with research for short exposure times, consideration of transition diagrams, new approximations for the coefficient of friction, and completely renewed load sharing factors. In 1991 Prof. Blok contributed an extension of the flash temperature formula which made it directly applicable to hypoid gears.

The integral temperature, presented in ISO/TR 13989-2, averages the flash temperature and supplements empirical influence factors to the hidden load sharing factor. The resulting value approximates the maximum contact temperature, thus yielding about the same assessment of scuffing risk as the flash temperature method of this part of ISO/TR 13989. The integral temperature method is less sensitive for those cases where there are local temperature peaks, usually in gearsets that have low contact ratio or contact near the base circle or other sensitive geometries.

The risk of scuffing damage varies with the properties of gear materials, the lubricant used, the surface roughness of tooth flanks, the sliding velocities and the load. In contrast to the relatively long time of development of fatigue damage, one single momentary overload can initiate scuffing damage of such severity that affected gears may no longer be used. According to Blok [12][13][14][15][16][17], high contact temperatures of lubricant and tooth surfaces at the instantaneous contact position may effect a break-down of the lubricant film at the contact interface.

The interfacial contact temperature is conceived as the sum of two components:

— the interfacial bulk temperature of the moving interface, which, if varying, does so only comparatively slowly. For evaluating this component, it may be suitably averaged from the two overall bulk temperatures of the two rubbing teeth. The latter two bulk temperatures follow from the thermal network theory [18].

— the rapidly fluctuating flash temperature of the moving faces in contact. Special attention has to be paid to the coefficient of friction. A common practice is the use of a coefficient of friction valid for regular working conditions, although it may be stated that at incipient scuffing the coefficient of friction has significantly higher values.

The complex relationship between mechanical, hydrodynamical, thermodynamical and chemical phenomena was the objective of extensive research and experiments, which may induce various empirical influence factors. A direct suppletion of empirical influence factors may enforce the related functional factors in the main formula to be fixated to average values. However, correct treatment of functional factors (e.g. coefficient of friction, load sharing factor, thermal contact coefficient) keeps the main formula intact, in confirmation with the experiments and practice.

Next to the maximum contact temperature, the progress of the contact temperature along the path of contact provides necessary information to the gear design.

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TECHNICAL REPORT

ISO/TR 13989-1:2000(E)

Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears —

Part 1:
Flash temperature method

1 Scope

This part of ISO/TR 13989 specifies methods and formulae for evaluating the risk of scuffing, based on Blok's contact temperature concept.

The fundamental concept according to Blok is applicable to all machine elements with moving contact zones. The flash temperature formulae are valid for a band-shaped or approximately band-shaped Hertzian contact zone and working conditions characterized by sufficiently high Péclet numbers.

2 Normative references

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The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 13989. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 13989 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

ISO 6336-1:1996, *Calculation of load capacity of spur and helical gears — Part 1: Basic principles, introduction and general influence factors*.

ISO 10300-1:—[1]), *Calculation of load capacity of bevel gears — Part 1: Introduction and general influence factors*.

ISO 10825:1995, *Gears — Wear and damage to gear teeth — Terminology*.

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this part of ISO/TR 13989, the terms and definitions given in ISO 1122-1 and ISO 10825 apply.

3.2 Symbols and units

The symbols used in this part of ISO/TR 13989 are given in Table 1. The units of length metre, millimetre and micrometre are chosen in accordance with common practice. To achieve a "coherent" system, the units for B_M, c_γ, X_M are adapted to the mixed application of metre and millimetre or millimetre and micrometre.

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[1]) To be published.

Table 1 — Symbols and units

Symbol	Description	Unit	Reference
a	centre distance	mm	Eq. (A.5)
b	facewidth, smaller value for pinion or wheel [a]	mm	Eq. (11)
b_{eff}	effective facewidth	mm	Eq. (12)
b_H	semi-width of Hertzian contact band	mm	Eq. (3)
B_M	thermal contact coefficient	$N/(mm^{\frac{1}{2}} \cdot m^{\frac{1}{2}} \cdot s^{\frac{1}{2}} \cdot K)$	Eq (A.13)
B_{M1}	thermal contact coefficient of pinion	$N/(mm^{\frac{1}{2}} \cdot m^{\frac{1}{2}} \cdot s^{\frac{1}{2}} \cdot K)$	Eq. (3)
B_{M2}	thermal contact coefficient of wheel	$N/(mm^{\frac{1}{2}} \cdot m^{\frac{1}{2}} \cdot s^{\frac{1}{2}} \cdot K)$	Eq. (3)
C_{a1}	tip relief of pinion	µm	Eq. (48)
C_{a2}	tip relief of wheel	µm	Eq. (46)
C_{eff}	optimal tip relief	µm	Eq. (46)
C_{eq1}	equivalent tip relief of pinion	µm	Eq. (B.2)
C_{eq2}	equivalent tip relief of wheel	µm	Eq. (B.3)
C_{f1}	root relief of pinion	µm	Eq. (B.3)
C_{f2}	root relief of wheel	µm	Eq. (B.2)
c_{M1}	specific heat per unit mass of pinion	J/(kg·K)	Eq. (9)
c_{M2}	specific heat per unit mass of wheel	J/(kg·K)	Eq. (10)
c_γ	mesh stiffness	N/(mm·µm)	Eq. (B.1)
d_1	reference diameter of pinion	mm	Eq. (34)
d_2	reference diameter of wheel	mm	Eq. (35)
d_{a1}	tip diameter of pinion	mm	Eq. (34)
d_{a2}	tip diameter of wheel	mm	Eq. (35)
E_1	modulus of elasticity of pinion	N/mm^2	Eq. (A.10)
E_2	modulus of elasticity of wheel	N/mm^2	Eq. (A.10)
E_r	reduced modulus of elasticity	N/mm^2	Eq. (A.9)
F_{ex}	external axial force	N	Eq. (18)
F_n	normal load in wear test	N	Fig. 1
F_t	nominal tangential force	N	Eq. (11)
H_1	auxiliary dimension	mm	Eq. (B.3)
H_2	auxiliary dimension	mm	Eq. (B.2)
h_{am1}	tip height in mean cone of pinion	mm	Eq. (43)
h_{am2}	tip height in mean cone of wheel	mm	Eq. (44)

Table 1 — **Symbols and units** (continued)

Symbol	Description	Unit	Reference
K_A	application factor	—	Eq. (11)
$K_{B\alpha}$	transverse load factor (scuffing)	—	Eq. (11)
$K_{B\beta}$	face load factor (scuffing)	—	Eq. (11)
$K_{H\alpha}$	transverse load factor (contact stress)	—	Eq. (15)
$K_{H\beta}$	face load factor (contact stress)	—	Eq. (14)
K_{mp}	multiple path factor	—	Eq. (11)
K_v	dynamic factor	—	Eq. (11)
m_n	normal module	mm	Eq. (B.2)
n_1	revolutions per minute of pinion	r/min	Eq. (5)
n_p	number of mesh contacts	—	Eq. (16)
Pe_1	Péclet number of pinion material	—	Eq. (9)
Pe_2	Péclet number of wheel material	—	Eq. (10)
Q	quality grade	—	Eq. (57)
Ra_1	tooth flank surface roughness of pinion	μm	Eq. (28)
Ra_2	tooth flank surface roughness of wheel	μm	Eq. (28)
R_m	cone distance of mean cone	mm	Eq. (A.16)
r_{m1}	reference radius in mean cone of pinion	mm	Eq. (43)
r_{m2}	reference radius in mean cone of wheel	mm	Eq. (44)
S_B	safety factor for scuffing	—	Eq. (100)
S_{FZG}	load stage (in FZG test)	—	Eq. (99)
t_1	contact exposure time of pinion	μs	Eq. (95)
t_2	contact exposure time of wheel	μs	Eq. (96)
t_c	contact exposure time at bend of curve	μs	Eq. (97)
t_{max}	longest contact exposure time	μs	Eq. (95)
u	gear ratio	—	Eq. (A.6)
u_v	virtual ratio	—	Eq. (B.6)
v_g	sliding velocity	m/s	Fig. 1
v_{g1}	tangential velocity of pinion	m/s	Eq. (3)
v_{g2}	tangential velocity of wheel	m/s	Eq. (3)
$v_{g\Sigma C}$	sum of tangential velocities in pitch point	m/s	Eq. (25)
v_t	pitch line velocity	m/s	Eq. (26)
w_{Bn}	normal unit load	N/mm	Eq. (3)
w_{Bt}	transverse unit load	N/mm	Eq. (5)

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Table 1 — **Symbols and units** (continued)

Symbol	Description	Unit	Reference
X_{but}	buttressing factor	—	Eq. (54)
X_{butA}	buttressing value	—	Eq. (51)
X_{butE}	buttressing value	—	Eq. (51)
X_G	geometry factor	—	Eq. (A.5)
X_J	approach factor	—	Eq. (3)
X_L	lubricant factor	—	Eq. (25)
X_M	thermo-elastic factor	$K \cdot N^{-3/4} \cdot s^{-1/2} \cdot m^{-1/2} \cdot mm$	Eq. (5)
X_{mp}	multiple mating pinion factor	—	Eq. (22)
X_R	roughness factor	—	Eq. (25)
X_S	lubrication system factor	—	Eq. (22)
X_W	structural factor	—	Eq. (94)
$X_{\alpha\beta}$	angle factor	—	Eq. (A.6)
X_Γ	load sharing factor	—	Eq. (3)
X_Θ	gradient of the scuffing temperature	—	Eq. (97)
z_1	number of teeth of pinion	—	Eq. (30)
z_2	number of teeth of wheel	—	Eq. (30)
α_{a1}	transverse tip pressure angle of pinion	°	Eq. (31)
α_{a2}	transverse tip pressure angle of wheel	°	Eq. (30)
α_t	transverse pressure angle	°	Eq. (34)
α_{wn}	normal working pressure angle	°	Eq. (A.2)
α_{wt}	transverse working pressure angle	°	Eq. (7)
α_{y1}	pinion pressure angle at arbitrary point	°	Eq. (29)
β	helix angle	°	Eq. (18)
β_b	base helix angle	°	Eq. (49)
β_{bm}	base helix angle in midcone	°	Eq. (50)
β_w	working helix angle	°	Eq. (A.2)
Γ_A	parameter on the line of action at point A	—	Eq. (24)
Γ_{AA}	parameter on the line of action at point AA	—	Eq. (68)
Γ_{AB}	parameter on the line of action at point AB	—	Eq. (66)
Γ_{AU}	parameter on the line of action at point AU	—	Eq. (49)
Γ_B	parameter on the line of action at point B	—	Eq. (31)
Γ_{BB}	parameter on the line of action at point BB	—	Eq. (70)
Γ_D	parameter on the line of action at point D	—	Eq. (32)
Γ_{DD}	parameter on the line of action at point DD	—	Eq. (72)
Γ_{DE}	parameter on the line of action at point DE	—	Eq. (67)

Table 1 — **Symbols and units** (continued)

Symbol	Description	Unit	Reference
Γ_E	parameter on the line of action at point E	—	Eq. (24)
Γ_{EE}	parameter on the line of action at point EE	—	Eq. (74)
Γ_{EU}	parameter on the line of action at point EU	—	Eq. (49)
Γ_M	parameter on the line of action at point M	—	Eq. (86)
Γ_y	parameter on the line of action at arbitrary point	—	Eq. (7)
γ_1	angle of direction of tangential velocity of pinion	—	Eq. (3)
γ_2	angle of direction of tangential velocity of wheel	—	Eq. (3)
δ_1	pitch cone angle of pinion	°	Eq. (37)
δ_2	pitch cone angle of wheel	°	Eq. (39)
ε_α	transverse contact ratio	—	Eq. (76)
ε_β	overlap ratio	—	Eq. (52)
η_{oil}	absolute (dynamic) viscosity at oil temperature	mPa·s	Eq. (27)
Θ_B	contact temperature	°C	Eq. (1)
Θ_{Bmax}	maximum contact temperature	°C	Eq. (2)
Θ_{fl}	flash temperature	K	Eq. (1)
Θ_{flm}	average flash temperature	K	Eq. (22)
Θ_{flmax}	maximum flash temperature	K	Eq. (2)
Θ_{flmaxT}	maximum flash temperature at test	K	Eq. (94)
Θ_M	bulk temperature	°C	Eq. (22)
Θ_{Mi}	interfacial bulk temperature	°C	Eq. (1)
Θ_{M1}	bulk temperature of pinion teeth	°C	Eq. (20)
Θ_{M2}	bulk temperature of wheel teeth	°C	Eq. (20)
Θ_{MT}	bulk temperature at test	°C	Eq. (94)
Θ_{oil}	oil temperature before reaching the mesh	°C	Eq. (22)
Θ_S	scuffing temperature	°C	Eq. (94)
Θ_{Sc}	scuffing temperature at long contact time	°C	Eq. (97)
λ_{M1}	heat conductivity of pinion	N/(s·K)	Eq. (9)
λ_{M2}	heat conductivity of wheel	N/(s·K)	Eq. (10)
μ	coefficient of friction in pin-and-ring test	—	Fig. 1
μ_m	mean coefficient of friction	—	Eq. (3)
ν_1	Poisson's ratio of pinion material	—	Eq. (A.10)
ν_2	Poisson's ratio of wheel material	—	Eq. (A.10)