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Calculation of load capacity of bevel gears -- Part 1: Introduction and general influence factors

Calcul de la capacité de charge des engrenages coniques -- Partie 1: Introduction et facteurs généraux d'influence

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Calculation of load capacity of bevel gears —

Part 1:
Introduction and general influence factors

Calcul de la capacité de charge des engrenages coniques —

Partie 1: Introduction et facteurs généraux d'influence

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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.

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

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 10300 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 10300-1 was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 2, *Gear capacity calculation*.

ISO 10300 consists of the following parts, under the general title *Calculation of load capacity of bevel gears*:

— *Part 1: Introduction and general influence factors*

— *Part 2: Calculation of surface durability (pitting)*

— *Part 3: Calculation of tooth root strength*

Annex A forms an integral part of this part of ISO 10300. Annex B and annex C are for information only.

Introduction

Parts 1, 2 and 3 of ISO 10300, taken together with ISO 6336-5, are intended to establish general principles and procedures for the calculation of the load capacity of bevel gears. Moreover, ISO 10300 has been designed to facilitate the application of future knowledge and developments, as well as the exchange of information gained from experience.

Several methods for the calculation of load capacity and various factors are specified by ISO 10300, whose guidelines are complex, yet flexible. There could be differences of up to 20 % to 25 % between the results of calculations carried out using method B with method B1 and method B2 with method C. The combined use of methods B2 and C, considered the methods of greater simplification, provides a more conservative safety factor. Detailed or simplified methods can be included, as appropriate, in application standards derived from ISO 10300 in the fields of industrial and marine gears. However, it must be stressed that the methods' use for specific applications demands not only experience with combined calculation methods, but also a realistic and knowledgeable appraisal of all relevant considerations, as well as appropriate safety factors.

The more detailed calculation methods of ISO 10300 are intended for the recalculation of the load capacity limits of gears where all important data, such as existing gear sets and completed gear designs, is known. The approximate methods of ISO 10300 are to be used for preliminary estimates of gear capacity where the final details of the gear design are as yet unknown.

The procedures covered by ISO 10300 are based on both testing and theoretical studies. However, the results obtained from its rating calculations may not be in good agreement with certain, previously accepted, gear-calculation methods.

ISO 10300 provides methods by which different gear designs can be compared. It is not intended to ensure the performance of assembled gear-drive systems. Neither is it intended for use by the average engineer. Rather, it is aimed at the experienced gear designer capable of selecting reasonable values for the factors in these formulae, based on knowledge of similar designs and on awareness of the effects of the items discussed.

Calculation of load capacity of bevel gears —

Part 1:
Introduction and general influence factors

1 Scope

The formulae in ISO 10300 are intended to establish uniformly acceptable methods for calculating the pitting resistance and bending-strength capacity of straight and helical (skew), zerol and spiral bevel gears except hypoid gears. They are applicable equally to tapered depth and uniform depth teeth.

The formulae take into account the known major factors influencing gear-tooth pitting and fractures at the root fillet, as well as allowing for the inclusion of new factors at a later date. The rating formulae are not applicable to other types of gear-tooth deterioration such as plastic yielding, micropitting, case crushing, welding, and wear. The bending-strength formulae are applicable to fractures at the tooth fillet, but not to those on the tooth-working profile surfaces, nor to failure of the gear rim or of the gear blank through the web and hub. Pitting resistance and bending-strength capacity rating systems for a particular category of bevel gear can be established by selecting proper values for the factors used in the general formulae. ISO 10300 is not applicable to bevel gears which have an inadequate contact pattern.

ISO 10300 is restricted to bevel gears whose virtual cylindrical gears have transverse contact ratios of $\varepsilon_{v\alpha} < 2$. The given relations are valid for gears of which the sum of addendum modification factors of pinion and gear is zero, i.e. the normal operating pressure angle of the gear pair is the same as the normal pressure angle of the basic rack.

NOTE Methods for the calculation of the load capacity of hypoid gears are indicated by the manufacturers of gear-cutting machines.

CAUTION — The user is cautioned that when the methods are used for large spiral and pressure angles, and for large face width $b > 10\ m_{mn}$, the calculated results of ISO 10300 should be confirmed by experience.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 10300. 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 10300 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 53:1998, *Cylindrical gears for general and heavy engineering — Standard basic rack tooth profile*.

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

ISO 1328-1:1995, *Cylindrical gears — ISO system of accuracy — Part 1: Definitions and allowable values of deviations relevant to corresponding 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 6336-5, *Calculation of load capacity of spur and helical gears — Part 5: Strength and quality of materials*.

ISO 10300-2, *Calculation of load capacity of bevel gears — Part 2: Calculation of surface durability (pitting)*.

ISO 10300-3, *Calculation of load capacity of bevel gears — Part 3: Calculation of tooth root strength*.

ISO/TR 10495, *Cylindrical gears — Calculation of service life under variable loads — Conditions for cylindrical gears according to ISO 6336*.

3 Terms and definitions

For the purposes of this part of ISO 10300, terms and definitions consistent with those given in ISO 53 and ISO 1122-1 apply.

4 Symbols and abbreviations

The symbols used in this part of ISO 10300 (see Table 1) are based on those of ISO 701, while also including symbols given in ISO 1328-1.

Table 1 — Symbols and abbreviations used in parts 1, 2 and 3 of ISO 10300

Symbol	Description or term	Unit
a_{v}	centre distance of virtual cylindrical gear	mm
a_{vn}	centre distance of virtual cylindrical gear in normal section	mm
b	face width	mm
b_{ce}	calculated effective face width	mm
b_{e}	effective face width	mm
Δb_{e}	heel increment of face width	mm
$\Delta b_{\mathrm{e}}{}'$	effective heel increment of face width	mm
Δb_{i}	toe increment of face width	mm
$\Delta b_{\mathrm{i}}{}'$	effective toe increment of face width	mm
c_{v}	dimensionless parameter	—
c_{γ}	mesh stiffness	N/(mm · µm)
$c_{\gamma 0}$	mesh stiffness for average conditions	N/(mm · µm)
c'	single stiffness (see ISO 6336-1)	N/(mm · µm)
$c_0{}'$	single stiffness for average conditions	N/(mm · µm)
d_{e}	outer pitch diameter	mm
d_{m}	mean pitch diameter	mm
d_{v}	reference diameter of virtual cylindrical gear	mm
d_{va}	tip diameter of virtual cylindrical gear	mm
d_{van}	tip diameter of virtual cylindrical gear in normal section	mm
d_{vb}	base diameter of virtual cylindrical gear	mm
d_{vbn}	base diameter of virtual cylindrical gear in normal section	mm
d_{vn}	reference diameter of virtual cylindrical gear in normal section	mm
f	distance to a line of contact	mm
f^*	referred distance to middle line of contact	—
$f_{\mathrm{f}\alpha}$	profile form deviation	µm
f_{max}	maximum distance to middle line of contact	mm
f_{pt}	single pitch deviation	µm
$f_{\mathrm{p\ eff}}$	effective pitch deviation	µm
f_{F}	load correction factor	—
g_{f0}	assumed distance in locating weakest section	mm
$g_{\mathrm{v}\alpha}$	length of path of contact of virtual cylindrical gear	mm
$g_{\mathrm{v}\alpha\mathrm{n}}$	length of path of contact of virtual cylindrical gear in normal section	mm
g_{xb}	distance between the centre of the cutter edge radius and the centreline of the gear measured along the tool reference plane	mm
g_{yb}	distance from centre of tooth tip edge radius to crown gear pitch surface measured in a direction perpendicular to pitch surface	mm

Table 1 (*continued*)

Symbol	Description	Unit
g_{za}	intermediate variable for calculating tooth strength factor	mm
g_{zb}	intermediate variable for calculating tooth strength factor	mm
g_J	intermediate variable for calculating tooth strength factor	mm
g_J'	intermediate variable for calculating tooth strength factor	mm
g_K	projected length of instantaneous line of contact in lengthwise direction of tooth	mm
g_η	length of action within the contact ellipse	mm
g_0	distance from centreline of crown gear (tool) space to tool centre tip edge radius measured in mean normal section	mm
g_0''	distance from mean section to centre of pressure measured in the lengthwise direction along the tooth	mm
h_{ae}	outer addendum	mm
h_{am}	mean addendum	mm
h_{aP}	addendum of the basic rack profile	mm
h_{a0}	tool addendum	mm
h_{fe}	outer dedendum	mm
h_{fP}	dedendum of the basic rack profile	mm
h_{fm}	mean dedendum	mm
h_{f0}	tool dedendum	mm
h_{Fa}	bending moment arm for tooth root stress (load application at tooth tip)	mm
h_N	load height from critical section	mm
k	summation index	—
k'	constant of location	—
l_b	length of contact line	mm
l_{bm}	length of middle line of contact	mm
l_{bm}'	projected length of middle line of contact	mm
m_{et}	outer transverse module	mm
m_{mn}	mean normal module	mm
m_{mt}	mean transverse module	mm
m_{red}	mass per mm facewidth reduced to the line of action of the dynamically equivalent cylindrical gears	kg/mm
m^*	relative individual gear mass per unit facewidth referred to line of action	kg/mm
n	rotational speed	min^{-1}
n_{E1}	resonance speed of pinion	min^{-1}
p	peak load	N/mm
pr	protuberance of the tool	mm
p_{max}	maximum peak load	N/mm
p^*	referred peak load	—

Table 1 (*continued*)

Symbol	Description	Unit
p_{et}	transverse base pitch of virtual cylindrical gear	mm
q	machining stock	mm
q	exponent in the formula for lengthwise curvature factor	—
q_s	notch parameter	—
q_{sT}	notch parameter of test gear	—
r_{c0}	cutter radius	mm
r_{mf}	tooth fillet radius at the mean section	mm
$r_{my\,0}$	mean transverse radius to point of load application	mm
$\Delta r_{y\,0}$	distance from pitch circle to point of load application in mean normal section	mm
s_{et}	transverse tooth thickness at the back cone	mm
s_{amn}	mean normal topland	mm
s_{mn}	mean normal circular thickness	mm
s_{pr}	amount of protuberance	mm
s_{mt}	mean transverse circular thickness	mm
s_{Fn}	tooth root chord in calculation section	mm
s_N	one-half tooth thickness at critical section	mm
u	gear ratio of bevel gear	—
u_v	gear ratio of virtual cylindrical gear	—
v_{et}	tangential speed at outer end (heel) of reference cone	m/s
$v_{et\,max}$	maximum pitch line velocity at operating pitch diameter	m/s
v_{mt}	tangential speed at reference cone at mid-facewidth	m/s
x_{hm}	profile shift coefficient	—
x_{sm}	thickness modification coefficient	—
x_N	pinion tooth strength factor	mm
y_p	running-in allowance for pitch error related to the smooth polished test piece	µm
y_J	location of point of load application for maximum bending stress on path of action	mm
y_3	location of point of load application on path of action	mm
y_α	running-in allowance for pitch error	µm
z	number of teeth	—
z_v	number of teeth of virtual cylindrical gear	—
z_{vn}	number of teeth of virtual cylindrical gear in normal section	—
A	auxiliary factor for dynamic factor	—
$A_m{}^*$	auxiliary value for load sharing factor	mm^2
$A_r{}^*$	auxiliary value for load sharing factor	mm^2

Table 1 (*continued*)

Symbol	Description	Unit
A_{sne}	outer tooth thickness allowance	mm
A_{t}^*	auxiliary value for load sharing factor	mm^2
B	auxiliary factor for dynamic factor	—
C	quality grade	—
C_{a}	tip relief	µm
C_{b}	correction factor for tooth stiffness for non-average conditions	—
C_{F}	correction factor for tooth stiffness for non-average conditions	—
C_{ZL},C_{ZR},C_{ZV}	factors for determining lubricant film factors	—
E	modulus of elasticity, Young's modulus	N/mm^2
E, G, H	auxiliary factors for tooth form factor	—
F	auxiliary factor for mid-zone factor	—
F_{mt}	nominal tangential force at reference cone at mid-facewidth	N
$F_{\mathrm{mt\,H}}$	decisive tangential force at reference cone at mid-facewidth	N
HB	Brinell hardness	—
K	constant; factor concerning tooth load	—
K_{v}	dynamic factor	—
K_{A}	application factor	—
K_{F0}	lengthwise curvature factor for bending stress	—
$K_{\mathrm{F\alpha}}$	transverse load factor for bending stress	—
$K_{\mathrm{F\beta}}$	face load factor for bending stress	—
$K_{\mathrm{H\alpha}}$	transverse load factor for contact stress	—
$K_{\mathrm{H\beta}}$	face load factor for contact stress	—
$K_{\mathrm{H\beta\text{-}be}}$	bearing factor	—
L	empirical constant used in stress correction formula	—
L_{a}	auxiliary factor for correction factor	—
M	empirical constant used in stress correction formula	—
N	reference speed for n_{E1}	—
N_{L}	number of load cycles	—
O	empirical constant used in stress correction formula	—
P	nominal power	kW
P_d	outer diametral pitch	inch^{-1}
Ra	= CLA = AA arithmetic average roughness	µm
R_{e}	outer cone distance	mm
R_{m}	mean cone distance	mm
Rz	mean roughness	µm
Rz_{T}	mean roughness of test gear	µm

Table 1 (*continued*)

Symbol	Description	Unit
Rz_{10}	mean roughness for gear pairs with ρ_{red} = 10 mm	µm
S_F	safety factor for bending stress (against breakage)	—
$S_{F\,min}$	minimum safety factor for bending stress	—
S_H	safety factor for contact stress (against pitting)	—
$S_{H\,min}$	minimum safety factor for contact stress	—
T	nominal torque	Nm
Y	tooth form factor	—
Y_i	inertia factor	—
Y_f	stress concentration and stress correction factor	—
Y_A	bevel gear adjustment factor	—
Y_B	bending stress factor	—
Y_C	compression stress factor	—
Y_{Fa}	tooth form factor for load application at tip	—
Y_{FS}	combined tooth form factor for generated gears	—
Y_J	bevel geometry factor (Method B2)	—
Y_K	bevel gear factor	—
Y_{LS}	load sharing factor (bending strength)	—
Y_{NT}	life factor of the standard test gear	—
Y_P	combined geometry factor	—
Y_R	surface factor of smooth specimen	—
Y_{RT}	surface factor of test gear with roughness of Rz_T = 10 µm	—
$Y_{R\,rel\,T}$	relative surface factor	—
Y_{Sa}	stress correction factor for load application at tooth tip	—
Y_{ST}	stress correction factor for dimensions of standard test gear	—
Y_X	size factor for tooth root stress	—
Y_δ	dynamic sensitivity factor of the gear to be determined	—
$Y_{\delta T}$	dynamic sensitivity factor of the standard test gear	—
$Y_{\delta\,rel\,T}$	relative sensitivity factor	—
Y_ε	contact ratio factor (tooth root)	—
Z_v	speed factor	—
Z_E	elasticity factor	—
Z_H	zone factor	—
Z_K	bevel gear factor (flank)	—
Z_L	lubricant factor	—
Z_{LS}	load sharing factor	—