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Gears — Calculation of load capacity of worm gears

Engrenages — Calcul de la capacité de charge des engrenages à vis

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Foreword

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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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 1, *Nomenclature and wormgearing*.

This first edition cancels and replaces ISO/TR 14521:2010, which has been technically revised.

The main changes compared to the previous edition are as follows:

— the orginal Clause 6 which focused on geometry has been deleted and ISO/TR 10828 has been referenced.

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.

Introduction

This document was developed for the rating and design of enclosed or open single enveloping worm gears with cylindrical worms, and worm-geared motors having either solid or hollow output shafts.

This document is only applicable when the flanks of the worm wheel teeth are conjugate to those of the worm threads.

The particular shapes of the rack profiles from tip to root do not affect the conjugacy when the worm and worm wheel hobs have the same profiles; thus worm wheels have proper contact with worms and the motions of worm gear pairs are uniform.

This document can apply to wormgearing with cylindrical helicoidal worms as defined in ISO/TR 10828 having the following thread forms: A, C, I, N, K.

Other than those mentioned in the three preceding paragraphs, no restrictions are placed on the manufacturing methods used.

In order to ensure proper mating and because of the many different thread profiles in use, it is generally desirable that worms and worm wheels be supplied by the same manufacturer.

In this document, the permissible torque for a worm gear is limited by considerations of surface stress (conveniently referred to as wear or pitting) or bending stress (referred to as strength) in both worm threads and worm wheel teeth, deflection of worm or thermal limitation.

Consequently, the load capacity of a pair of gears is determined using calculations concerned with all criteria described in the scope and 6.4. The permissible torque on the worm wheel is the least of the calculated values.

Gears — Calculation of load capacity of worm gears

1 Scope

This document specifies formulae for calculating the load capacity of cylindrical worm gears and covers load ratings associated with wear, pitting, worm deflection, tooth breakage and temperature. Scuffing and other failure modes are not covered by this document.

The load rating and design procedures are only valid for tooth surface sliding velocities, $\vec{v}_g$, less than or equal to 25 m/s and contact ratios greater than 2,1. For wear, load rating and design procedures are only valid for tooth surface sliding velocities which are above 0,1 m/s. The rules and recommendations for the dimensioning, lubricants or materials selected by this document only apply to centre distances of 50 mm and larger. For centre distances below 50 mm, method A applies.

The choice of appropriate methods of calculation requires knowledge and experience. This document is intended for use by experienced gear designers who can make informed judgements concerning factors. It is not intended for use by engineers who lack the necessary experience. See 4.7.

WARNING — The geometry of worm gears is complex, therefore the user of this document is encouraged to make sure that a valid working geometry has been established.

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 1122-2, *Vocabulary of gear terms — Part 2: Definitions related to worm gear geometry*

ISO 6336-6, *Calculation of load capacity of spur and helical gears — Part 6: Calculation of service life under variable load*

DIN 3974-1, *Accuracy of worms and wormgears — Part 1: General bases*

DIN 3974-2, *Accuracy of worms and wormgears — Part 2: Tolerances for individual errors*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1
actual gear
worm gear set designed by this document

3.2 Symbols

NOTE Where applicable, the symbols are in accordance with ISO 701.

Table 1 — Symbols for worm gears

Symbols	Description	Unit	Figure	Formula
a	centre distance	mm	Figure 1	
a_1	centre distance of the gear concerned	mm	Figure 1	
a_0, a_1, a_2	oil sump temperature coefficients			(118) to (124)
a_T	centre distance of standard reference gear	mm	Figure 1	
a_V	centre distance of a gear operating or test experiences are available	mm	Table 4	
b_{2H}	effective wheel facewidth	mm		
$b_{2H,std}$	standard effective worm wheel facewidth	mm		(10)
b_{2R}	wheel rim width	mm		(132)
b_H	half Hertzian contact width	mm	Annex D	(D.2)
c_k	coefficient for heat transition coefficient			(133)
c_{oil}	specific heat capacity of the oil (for temperature calculation with spray lubrication)	Ws/(kg.K)		(128)
c_α	proximity value for the viscosity pressure exponent α	m^2/N		(22)/(24)
$d_{a\,1}$	worm tip diameter	mm		(89)
$d_{a\,2}$	worm wheel throat diameter	mm		
$d_{e\,2}$	worm wheel outside diameter	mm		
$d\vec{F}$	force transmitted by a segment of the contact line	N	Figure B.2	(B.3)
dl	length of contact line segment	mm		(B.1) to (B.6)
$d_{f\,1}$	worm root diameter	mm		(104)
$d_{f\,2}$	worm wheel root diameter	mm		(111)
d_{m1}	worm reference diameter	mm		
d_{m2}	worm wheel reference diameter	mm		(41) to (43)
d_{m1T}	reference diameter of the worm, from standard reference gear	mm	Table 4	(44), (45)
d_{m2T}	reference diameter of the wheel, from standard reference gear	mm	Table 4	
$\vec{e}_x$	unit vector pointing in direction of the x-axis	mm		(B.4)
f_h	worm wheel face width factor for the parameter for the minimum mean lubricant film thickness	—		(16)
f_p	worm wheel face width factor for the parameter for the mean Hertzian stress	—		(17)
Δf	relative deviation between a quantity of the gear concerned and a reference gear	—	Figure 1	
Δf_T	relative deviation between the centre distance of the gear concerned and the standard reference gear	—	Figure 1	
Δf_V	relative deviation between the centre distance of the gear concerned and a gear operating or test experiences are available	—	Figure 1	

Table 1 *(continued)*

Symbols	Description	Unit	Figure	Formula
h_{am1}	worm tooth reference addendum in axial section	mm		(86)
h_{min}	minimum lubricant film thickness	µm		(C.1)
$h_{min\ m}$	minimum mean lubricant film thickness	µm		(21)
h^*	parameter for minimum mean lubricant film thickness	—		(14)/(15)
h_T^*	parameter for minimum mean lubricant film thickness of the standard reference gear	—	Table 4	
k	lubricant constant	1/K		(27)/(29)
l_1	spacing of the worm shaft bearings	mm		(103)
l_{11}, l_{12}	bearing spacing of the worm shaft	mm	Figure 5	(103)
$m_{x\,1}$	axial module	mm		
Δm_{lim}	material loss limit	mg		(88)
Δs	tooth thickness loss	mm		(111)
Δs_{lim}	allowable tooth thickness loss	mm		(87)
$\vec{n}$	normal vector			(B.5)
n_1	rotational speed of the worm shaft	min^{-1}		
p_H	Hertzian stress	N/mm^2		(B.1)/(B.6)
p_{Hm}	Hertzian stress; mean value for the total contact area	N/mm^2		(B.7)
p_m^*	parameter for the mean Hertzian stress	—		(11)/(12)/(B.8)
p_{mT}^*	parameter for the mean Hertzian stress of the standard reference gear	—	Table 4	
q_1	diameter quotient	mm		
$\vec{r}$	radius from the axis of the worm wheel to the contact point B	mm		(B.4)
s_{f2}	mean tooth root thickness of the wheel teeth in the spur section	mm		(111)
s_{ft2}	mean tooth root thickness of the wheel teeth in the spur section	mm		(111)
s_{gB}	sliding path of the worm flanks within the Hertzian contact of the wheel flank per number of cycles of the wheel, around the contact point (local value)	mm		(D.3)/(D.5)
s_{gm}	mean sliding path	mm		(D.7)
s_{m2}	tooth thickness at the reference diameter of the worm wheel	mm		(111)
s_K	rim thickness	mm	Figure 6	(113)
s_{Wm}	wear path inside of the required life expectancy	mm		(30)/(D.1)
s_{mx1}	worm tooth thickness in axial section	mm		
s_{mx1}^*	worm tooth thickness in axial section coefficient	—		(111)
s^*	parameter for the mean sliding path	—		(17)/(18)/(D.8)
s_T^*	parameter for the mean sliding path of the standard reference gear	—	Table 4	
Δs	tooth thickness loss			(111)

Table 1 *(continued)*

Symbols	Description	Unit	Figure	Formula
Δs_{lim}	allowable tooth thickness loss			(87)/(111)
$t_{contact}$	time of contact	s		(D.2)
u	gear ratio			(1)
u_T	gear ratio of the standard reference gear		Table 4	
$\vec{v}_1$	velocity of a flank point of the worm	m/s	Figure B.1	
$\vec{v}_2$	velocity of a flank point of a worm wheel	m/s	Figure B.1	
v_{1n}	worm velocity component normal to the contact line	m/s	Figure B.2	
v_{2n}	wheel velocity component normal to the contact line	m/s	Figure B.2	(D.2)
$\vec{v}_{gB}$	sliding velocity normal to the line of contact in flank direction	m/s		(D.3)/(D.5)/(D.6)
v_g	sliding velocity at reference diameter	m/s		(9)/(49)/(50)/(51)/ (H.2)/(H.3)/(H.5)
v_{ref}	reference sliding velocity	m/s		(H.2) to (H.5)
$v_{\Sigma n}$	sum velocity in normal direction	m/s		(11)/(C.4)
x_2	worm wheel profile shift coefficient	—		
z_1	number of threads in worm	—		
z_2	number of teeth in worm wheel	—		
A	coefficient for kinematic viscosity			(33)
A_{fl}	total flank surface of the worm wheel	mm^2		(89)
A_R	dominant cooled surface of the gear set	m^2		(132)
B	coefficient for kinematic viscosity	—		(34)
B	coefficient for h^*	mm		(14)
E_1	modulus of elasticity of the worm	N/mm^2		
E_2	modulus of elasticity of the worm wheel	N/mm^2		
E_{red}	equivalent modulus of elasticity	N/mm^2	Table 4	(20)
F_{xm1}	axial force to the worm shaft	N		(4)/(7)
F_{xm2}	axial force to the worm wheel	N		(3)/(6)
F_{rm1}	radial force to the worm shaft	N		(5)
F_{rm2}	radial force to the worm wheel	N		(11)
F_{tm1}	circumferencial or tangential force to the worm shaft	N		(4)/(6)
F_{tm2}	circumferencial or tangential force to the worm wheel	N		(3)/(7)
dF/dl	specific loading	N/mm		(C.5)
J_{0T}	reference wear intensity	—	Figure 4	(69) to (79)
$J_{0I}, J_{0II}, J_{0III}$	reference wear intensity for stage I, II, III	—		(H.6) to (H.7)
J_W	wear intensity	—		(68)
J_{WP}	wear intensity	—		(H.6)
K_n	rotational speed factor/wheel bulk temperature	—		(135)
$K_{H\alpha}$	transverse load distribution factor	—		6.2.3
$K_{H\beta}$	longitudinal load distribution factor	—		6.2.3
K_S	size factor/wheel bulk temperature	—		(137)

Table 1 *(continued)*

Symbols	Description	Unit	Figure	Formula
K_A	application factor	—		6.2.1
K_v	dynamic factor	—		6.2.2
K_W	lubricant film thickness parameter	—		(80)
K_ν	viscosity factor/wheel bulk temperature	—		(136)
K_1	factor	—		(G.5)
L_h	life time	h		
N_L	number of stress cycles of the worm wheel	—		(31)
N_{LI}, N_{LII}, N_{LIII}	number of stress cycles of the worm wheel for stage I to III	—		(H.1)
N_S	number of starts per hour	—		(70)
P_1	input power to the worm shaft	W		
P_2	output power from the worm wheel shaft	W		
P_K	cooling capacity of the oil with spray lubrication	W		(127) (125)
P_V	total power loss of the worm gear unit	W		(38)
P_{V0}	idle running power loss	W		(38)/(39)/(G.1)
$P_{Vz1\text{-}2}$	meshing power loss in reducer	W		(62)
$P_{Vz2\text{-}1}$	meshing power loss in increaser	W		(64)
P_{VD}	sealing power loss	W		(44)/(45)
P_{VLP}	bearing power loss through loading	W		(40) to (43)
Q_{oil}	spray quantity	m^3/s		(127)
Ra_1	arithmetic mean roughness for worm	μm	Table 4	
Ra_T	arithmetic mean roughness for reference gear	μm		(62)
Rz_1	mean roughness depth	μm		7.4.6
S_F	tooth breakage safety factor	—		(106)
$S_{F\,min}$	minimum tooth breakage safety factor	—		(107)
S_H	pitting safety factor	—		(91)
S_{Hmin}	minimum pitting safety factor	—		(92)
S_T	temperature safety factor	—		(115)/(125)
$S_{T\,min}$	minimum temperature safety factor	—		(116)/(126)
S_W	wear safety factor	—		(65)
$S_{W\,min}$	minimum wear safety factor	—		(66)
S_δ	deflection safety factor	—		(101)
$S_{\delta\,min}$	limit of deflection safety factor	—		(102)
T_1	input torque to the worm shaft	Nm		(1)
T_{1N}	nominal input torque to the worm shaft	Nm		(1)
T_2	output torque from the worm wheel	Nm		(2)/(B.4)/(B.5)
T_{2N}	nominal output torque from the worm wheel	Nm		(2)
V_{SUMn}	sum of velocities at contact point			(C.1)
W_H	—			(84)/(85)
W_{ML}	material — lubricant factor	—	Table 7	
W_{NS}	start factor	—		(83)
W_P	damage factor	—		(H.8)
W_S	lubricant structure factor	—		(81)/(82)

Table 1 *(continued)*

Symbols	Description	Unit	Figure	Formula
Y_F	form factor/tooth breakage	—		(110)
Y_G	geometry factor/coefficient of friction	—		(59)/(60)
Y_K	rim thickness factor/tooth breakage	—		(113)
Y_{NL}	life factor/tooth breakage	—	Figure 7 a)/b)	Table 11
Y_R	roughness factor/coefficient of friction	—		(61)/(62)
Y_S	size factor/coefficient of friction	—		(57)/(58)
Y_W	material factor/coefficient of friction	—		
Y_{ε}	contact factor/tooth breakage	—		(109)
$Y\gamma$	lead factor/tooth breakage	—		(112)
Z_h	life factor/pitting	—		(94)
Z_{oil}	lubricant factor/pitting	—		(100)
Z_S	size factor/pitting	—		(96)/(97)
Z_u	gear ratio factor	—		(98)/(99)
Z_v	velocity factor/pitting	—		(95)
α	pressure viscosity factor	m^2/N		6.6
α_L	heat transition coefficient for immersed wheel teeth	$W/(m^2K)$		(133)
α_n	normal pressure angle	°		
α_0	normal pressure angle			(5), (86)
γ_{m1}	reference lead angle of worm	°		(86)
δ_{lim}	limiting value of deflection	mm		(105)
δ_m	incurred deflection	mm		(103)/(104)
δ_{Wn}	flank loss from wheel through abrasive wear in the normal section	mm		(67)
$\delta_{W\,lim}$	limiting value of flank loss	mm		(90)
$\delta_{W\,lim\,n}$	limiting value of flank loss in normal section	mm		(86) to (88)
η_{ges}	total efficiency in reducer	—		(35)
$\eta_{ges1\text{-}2}$	total efficiency worm driving wheel	—		(35)
$\eta_{ges2\text{-}1}$	total efficiency wheel driving worm	—		(36)
η'_{ges}	total efficiency in increaser	—		(36)
$\eta_{z1\text{-}2}$	gear efficiency in reducer	—		(46)/(63)
$\eta_{z2\text{-}1}$	gear efficiency in increaser	—		(47)/(64)
η_{0M}	dynamic viscosity of lubricant at ambient pressure and wheel bulk temperature	Ns/m^2		(25)/(C.1)
θ	temperature	°C		
$\Delta\theta$	temperature difference between oil sump and worm wheel bulk temperature	°C		(131)
θ_{in}	oil entrance temperature	°C		(129)
θ_0	ambient temperature	°C		
θ_{oil}	spray temperature	°C		(129)
$\Delta\theta_{oil}$	oil temperature difference between input and output cooling system	°C		(129)
θ_M	wheel bulk temperature	°C		(130)/(134)
θ_S	oil sump temperature	°C		(117)/(119)
$\theta_{S\,lim}$	limiting value of oil sump temperature	°C		(115)

