DRAFT INTERNATIONAL STANDARD ISO/DIS 14521.2

ISO/TC **60**/SC **1** Secretariat: **BSI**

Voting begins on: **2006-07-03** Voting terminates on: **2006-09-04**

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Gear — Calculation of load capacity of wormgears

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

ICS 21.200

To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.

Pour accélérer la distribution, le présent document est distribué tel qu'il est parvenu du secrétariat du comité. Le travail de rédaction et de composition de texte sera effectué au Secrétariat central de l'ISO au stade de publication.

Contents

Page

Foreword ... iv
Introduction ... iv
1 Scope ... 1
2 Normative references ... 1
3 Symbols and Terminology ... 1
4 Formulae for calculation of dimensions ... 10
5 General ... 16
6 Geometrical data to be known for calculation ... 21
7 Forces, speeds and parameters for the calculation of stresses ... 23
8 Efficiency and power loss ... 30
9 Wear load capacity ... 37
10 Surface durability (pitting resistance) ... 42
11 Deflection ... 44
12 Tooth root strength ... 46
13 Temperature safety factor ... 49
14 Determination of the wheel bulk temperature ... 52
Annex A (informative) **Notes on physical parameters** ... 55
Annex B (normative) **Methods for the determination of the parameters** ... 56
Annex C (informative) **Lubricant film thickness according to EHL - theory** ... 60
Annex D (normative) **Wear path definitions** ... 62
Annex E (informative) **Notes on calculation wear** ... 65
Annex F (informative) **Notes on tooth root strength** ... 66
Annex G (informative) **The utilisation of existing tooling for machining of worm wheel teeth** ... 67
Annex H (informative) **Adaptation of equations for the reference gear to own results of measurements** ... 70
Annex I (informative) **Life time estimation for worm gears with a high risk of pitting damage** ... 73
Annex J (informative) **Examples** ... 75
Bibliography ... 81

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 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14521 was prepared by Technical Committee ISO/TC 60, *Gears*, Subcommittee SC 1, *Nomenclature and wormgearing*.

Introduction

This standard 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 standard 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 so that worm wheels have proper contact with worms and the motions of worm gear pairs are uniform.

This standard can apply to worm gearing with cylindrical helicoidal worms having the following thread forms: A, C, I, N, K.

Other than the requirements of 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 worm and worm wheel are supplied by the same manufacturer.

In this standard, the permissible torque for a worm gear is limited either by consideration of surface stress (conveniently referred as wear or pitting) or bending stress (referred 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 7.3. The permissible torque on the worm wheel is the least of the calculated values.

Gears — Calculation of load capacity of wormgears

1 Scope

This International Standard specifies equations 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 standard.

The load rating and design procedures are valid for worm rotational speeds up to 5000 r/min, sliding velocities over tooth surface up to 25 m/s and contact ratios equal to or greater than 2,1. For wear sliding velocities over tooth surfaces should not be bellow 0,1 m/s.

The rules and recommendations for the dimensioning, lubricants or materials selected by this standard only apply to centre distances of 50 mm and larger. For centre distances below 50 mm method A should be applied.

The choice of appropriate methods of calculation requires knowledge and experience. This standard is intended for use by experienced gear designers who are able to make informed judgements concerning factors. It is not intended for use by engineers who lack the necessary experience. See 5.4.

The geometry of worm gears is complex therefore the user of this standard is induced to be sure that a working geometry without errors has been established.

2 Normative references

The following referenced documents are indispensable for the application 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 701:1998, *International gear notations — Symbols for geometrical data*

ISO 1122-2:1998, *Vocabulary of gear terms — Part: 2 Definitions related to worm gears geometry*

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

ISO/TR 10828:1997, *Worm gears — Geometry of worm profiles*

DIN 3974-1:1995, *Accuracy for worms and wormgears — Part 1: General basis*

DIN 3974-2:1995, *Accuracy for worms and wormgears — Part 2: Tolerances for individual errors*

3 Symbols and Terminology

3.1 Symbols

NOTE Where applicable, the symbols are in accordance with ISO 701 and the definitions are in accordance ISO 1122-2.

Table 1 — Symbols for worm gears

Symbols	Description	Units	Figures	Equation Number
a	centre distance	mm		38/39
a_0, a_1, a_2	oil sump temperature coefficients, calculated according to method C	-		157 to 163
a_{min}, a_{max}	minimum and maximum centre distance for tooling selection	mm		G.2/G.3
a_T	centre distance of standard reference gear	mm		
b_1	worm facewidth	mm		22
b_2	facewidth of the wheel as specified in DIN 3975	mm		36
b_{2H}	effective wheel facewidth	mm	Fig. 4	
b_{2R}	wheel rim width	mm	Fig. 4	
b_H	half hertzian contact width	mm	Fig.19	
c_1,c_2	tip clearance	mm		
c_1^*,c_2^*	tip clearance coefficient in axial section	mm		
c_{oil}	specific heat capacity of the oil (for temperature calculation with spray lubrication)	Ws/(kg.K)		167
c_α	proximity value for the viscosity pressure exponent α	m^2/N		61/63
$d_{a\,1}$	worm tip diameter	mm		13
$d_{a\,2}$	worm wheel tip diameter	mm		34
$d_{b\,1}$	base diameter of involute helicoid (for I profile)	mm		21
$d_{e\,2}$	worm wheel outside diameter	mm		35
dF	force transmitted by a segment of the contact line	N	Fig. B.2	B.3
dl	length of contact line segment	mm		B.1
$d_{f\,1}$	worm root diameter	mm		14
$d_{f\,2}$	worm wheel root diameter	mm		33
d_{m1}	worm reference diameter	mm	Fig. 2/5	9
d_{m1T}	reference diameter of the worm, from standard reference gear	mm		
d_{m2}	worm wheel reference diameter	mm	Fig 3/5	24
d_{m2T}	reference diameter of the wheel, from standard reference gear	mm		
d_{w1}	worm pitch diameter	mm		40
d_{w2}	worm wheel pitch diameter	mm		41
$e_{mx\,1}$	worm reference tooth space width in axial section	mm	Fig. 2	16
e_{n1}	worm normal tooth space width in normal section	mm		18
e_{m2}	worm wheel tooth space width in mid-plane section	mm		27
h_1	worm tooth depth	mm		10
h_2	worm wheel tooth depth	mm		31
h_{am1}	worm tooth reference addendum in axial section	mm	Fig. 5	11
h_{am2}	worm wheel tooth reference addendum in mid-plane section	mm	Fig. 5	29

Symbols	Description	Units	Figures	Equation Number
h^*_{am1}	worm tooth reference addendum coefficient in axial section	-		11
h^*_{am2}	worm wheel tooth reference addendum coefficient in mid-plane section	-		29
h_{e2}	worm wheel tooth external addendum	mm		32
h_{fm1}	worm tooth reference dedendum in axial section	mm		12
h_{fm2}	worm wheel tooth reference dedendum in mid-plane section	mm		30
h^*_{fm1}	worm tooth reference dedendum coefficient in axial section	-		
h^*_{fm2}	worm wheel tooth reference dedendum coefficient in mid-plane section	-		30
h_{min}	minimum lubricant film thickness	µm		C.1
$h_{\mathrm{min\ m}}$	minimum mean lubricant film thickness	µm		60
h^*	parameter for minimum mean lubricant film thickness	-		54/55
h^*_{T}	parameter for minimum mean lubricant film thickness of the standard reference gear	-		
j_{x}	axial backlash	mm		
k	lubricant constant	1/K		66/68
k^*	mean heat transition coefficient	W/(m²·K)		
l_1	spacing of the worm shaft bearings	mm		
l_{11}, l_{12}	bearing spacing of the worm shaft	mm	Fig. 11	
m_{max}	maximum axial module for tooling selection	mm	Fig. 11	G.4
m_{min}	minimum axial module for tooling selection	mm		G.5
m_{xhob}	axial module for tooling selection	mm		Annex G
m_{n}	normal module	mm		8
$m_{\mathrm{x\,1}}$	axial module	mm		2/G.1
Δm	material loss	mg		
Δm_{lim}	material loss limit	mg		
n_1	rotational speed of the worm shaft	min^{-1}		
n_2	rotational speed of the wheel	min^{-1}		
N_{S}	number of starts per hour			109
p_0	environmental pressure	$\mathrm{N/mm}^2$		
p_{b1}	base cylinder pitch for I profile	mm		22
p_{Hm}	hertzian stress; mean value for the total contact area	$\mathrm{N/mm}^2$		B.7
p^*_{m}	parameter for the mean hertzian stress	-		52/53
p^*_{mT}	parameter for the mean hertzian stress of the standard reference gear	-		
p_{n1}	normal pitch	mm		7
p_{t2}	transverse pitch	mm		25
$p_{\mathrm{x\,1}}$	axial pitch	mm	Fig. 2	1
$p_{\mathrm{z\,1}}$	lead of worm threads	mm		3

Symbols	Description	Units	Figures	Equation Number
q_1	diameter factor	mm		4
q_{hob}	diameter factor for hob	mm		Annex G
r_{g2}	worm wheel throat radius	mm		37
s_2	reference tooth thickness of the wheel teeth in the spur section	mm		150
s_{f2}	mean tooth root thickness of the wheel teeth in the spur section	mm		150
s_{ft2}	mean tooth root thickness of the wheel teeth in the spur section	mm		150
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	Fig. 3	26
s_K	rim thickness	mm	Fig. 12	
s_{Wm}	wear path inside of the required life expectancy	mm		68/D.1
s_{mx1}	worm tooth thickness in axial section	mm	Fig. 2	15
s^*_{mx1}	worm tooth thickness in axial section coefficient	-		15
s_{n1}	normal worm tooth thickness in normal section	mm		17
s^*	parameter for the mean sliding path	-		56/57/D.8
s^*_T	parameter for the mean sliding path of the standard reference gear	-		
Δs	tooth thickness loss	mm		
u	gear ratio			42
u_T	gear ratio of the standard reference gear			
v_1	velocity of a flank point of the worm	m/s	Fig. B.1	59
v_2	velocity of a flank point of a worm wheel	m/s	Fig. B.1	59
v_{1n}	worm velocity component normal to the contact line	m/s	Fig. B.2	
v_{2n}	wheel velocity component normal to the contact line	m/s	Fig. B.2	
$\vec{V}_{gB}$	sliding velocity at the reference diameter in flank direction	m/s		88/89/90/E .6
$\vec{v}_g$	sliding velocity at mean reference diameter	m/s		51
v_Σ	sum velocity	m/s		52
$v_{\Sigma n}$	sum velocity in normal direction	m/s		52
x_2	worm wheel profile shift coefficient	-		28
x_{2max}	maximum worm wheel profile shift coefficient for tooling selection	-		H.3
x_{2min}	minimum worm wheel profile shift coefficient for tooling selection	-		H.3
z_1	number of threads in worm	-		
z_2	number of teeth in worm wheel	-		
A	coefficient for kinematic viscosity			72

Symbols	Description	Units	Figures	Equation Number
A_{ges}	free surface of the gear housing	m^2		
A_{fl}	total flank surface of the worm wheel	mm^2		128
A_R	dominant cooled surface of the gear set	m^2		171
B	coefficient for kinematic viscosity	-		73
c	immersion factor	-		
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		59
E_{steel}	modulus of elasticity for steel	N/mm^2		59
F_{xm1}	axial force to the worm shaft	N		46/49
F_{xm2}	axial force to the worm wheel	N		45/48
F_{rm1}	radial force to the worm shaft	N		47
F_{rm2}	radial force to the worm wheel	N		50
F_{tm1}	circumferencial or tangential force to the worm shaft	N		45/48
F_{tm2}	circumferencial or tangential force to the worm wheel	N		46/49
dF/db	specific loading	N/mm		
J_{OT}	reference wear intensity	-	Fig. 10	108 to 118
J_W	wear intensity	-		107
K_n	rotational speed factor / wheel bulk temperature	-		174
$K_{H\alpha}$	transverse load distribution factor	-		
$K_{H\beta}$	longitudinal load distribution factor	-		
K_S	size factor / wheel bulk temperature	-		176
K_A	application factor	-		
K_v	dynamic factor	-		
K_W	lubricant film thickness parameter	-		119
K_ν	viscosity factor / wheel bulk temperature	-		175
L_h	life time	h		
N_L	number of stress cycles of the worm wheel	-		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		166
P_V	total power loss of the worm gear unit	W		77
P_{VO}	idle running power loss	W		77/78/H.1
P_{Vz1-2}	meshing power loss in reducer	W		102
P_{Vz2-1}	meshing power loss in increaser	W		103
P_{VD}	sealing power loss	W		83/84
P_{VLP}	bearing power loss through loading	W		79 to 82
Q_{oil}	spray quantity	m^3/s		
Ra_1	arithmetic mean roughness	µm		
Ra_T	arithmetic mean roughness for reference gear	µm		77

Symbols	Description	Units	Figures	Equation Number
Rz_1	mean roughness depth	µm		
S_F	tooth breakage safety factor	-		145
$S_{F\ min}$	minimum tooth breakage safety factor	-		146
S_H	pitting safety factor	-		130
S_T	temperature safety factor	-		154/164
$S_{T\ min}$	minimum temperature safety factor	-		155/165
S_W	wear safety factor	-		104
$S_{W\ min}$	minimum wear safety factor	-		105
S_δ	deflection safety factor	-		140
$S_{\delta\ lim}$	limit of deflection safety factor	-		141
T_1	input torque to the worm shaft	Nm		43
T_{1N}	nominal input torque to the worm shaft	Nm		43
T_2	output torque from the worm wheel	Nm		44/B.4/ B.5
T_{2N}	nominal output torque from the worm wheel	Nm		44
W_H	pressure factor	-		123/124
W_{ML}	material - lubricant factor	-		
W_{NS}	start factor	-		122
W_S	lubricant structure factor	-		120/121
Y_F	form factor / tooth breakage	-		148/149
Y_G	geometry factor / coefficient of friction	-		98/99
Y_K	rim thickness factor / tooth breakage	-		152
Y_{NL}	life factor / tooth breakage	-	Fig 13a/b	Table 11
Y_R	roughness factor / coefficient of friction	-		100/101
Y_S	size factor / coefficient of friction	-		96/97
Y_W	material factor / coefficient of friction	-		
Y_ε	contact factor / tooth breakage	-		148
Y_γ	lead factor / tooth breakage	-		151
Z_h	life factor / pitting	-		133
Z_{oil}	lubricant factor / pitting	-		139
Z_S	size factor / pitting	-		135/136
Z_u	gear ratio factor	-		137/138
Z_v	velocity factor / pitting	-		134
α	pressure viscosity factor	m^2/N		
α_0	axial pressure angle	°		
α_L	heat transition coefficient for immersed wheel teeth	$W/(m^2K)$		172
α_n	normal pressure angle	°		19
β_{m1}	reference helix angle of worm	°		6
γ_{m1}	reference lead angle of worm	°		5
γ_{b1}	base lead angle of worm thread (for I profile)	°		19

Symbols	Description	Units	Figures	Equation Number
$\delta_{\lim}$	limiting value of deflection	mm		144
δ_{m}	incurred deflection	mm		142/143
δ_{Wn}	flank loss from wheel through abrasive wear in the normal section	mm		106
$\delta_{W\ lim}$	limiting value of flank loss	mm		129
$\delta_{W\ lim\ n}$	limiting value of flank loss in normal section	mm		125 to 127
η_{ges}	total efficiency in reducer	-		74
η'_{ges}	total efficiency in increaser	-		75
η_{z1-2}	gear efficiency in reducer	-		85
η_{z2-1}	gear efficiency in increaser	-		86
η_{0M}	dynamic viscosity of lubricant at ambient pressure and wheel bulk temperature	Ns/m^2		64
θ	temperature	°C		
$\Delta\theta$	temperature difference between oil sump and worm wheel bulk temperature	°C		170
θ_{in}	oil entrance temperature	°C		
θ_{out}	oil exit temperature	°C		
θ_{0}	ambient temperature	°C		
θ_{oil}	spray temperature	°C		
$\Delta\theta_{oil}$	oil temperature difference between input and output cooling system	°C		168
θ_{M}	wheel bulk temperature	°C		169/173
θ_{S}	oil sump temperature	°C		156/158
$\theta_{S\ lim}$	limiting value of oil sump temperature	°C		
μ_{0T}	base coefficient of friction	-		88 to 90
μ_{zm}	mean tooth coefficient of friction	-		87
ν_{1}	POISSON ratio of the worm	-		
ν_{2}	POISSON ratio for the worm wheel	-		
ν_{θ}	kinematic viscosity at oil temperature θ	mm^2/s		71
ν_{40}	kinematic viscosity at 40 °C	mm^2/s		71
ν_{100}	kinematic viscosity at 100 °C	mm^2/s		
ν_{M}	kinematic viscosity at wheel bulk temperature	mm^2/s		64
ρ	profile radius of the grinding disk for C type	mm		
ρ_{oil}	lubricant density	kg/dm^3		
ρ_{oil15}	lubricant density at 15 °C	kg/dm^3		65
ρ_{oilM}	lubricant density at wheel bulk temperature	kg/dm^3		64
ρ_{red}	equivalent radius of curvature	mm		B.2
ρ_{z}	friction angle for the tooth coefficient of friction	°		
ρ_{Rad}	material density of the wheel	mg/mm^3		
$\Delta_{s\ lim}$	allowable tooth thickness loss	mm		126

Symbols	Description	Units	Figures	Equation Number
$\sigma_{H\ lim\ T}$	pitting strength	N/mm^2		
σ_H	contact stress	N/mm^2		132
σ_{Hm}	mean contact stress	N/mm^2		58
σ_{HG}	limiting value for the mean contact stress	N/mm^2		132
τ_F	shear stress at tooth root	N/mm^2		147
$\tau_{F\ lim\ T}$	shear endurance strength	N/mm^2		
τ_{FG}	limiting value for shear stress at tooth root	N/mm^2		153
ω_2	angular velocity	s^{-1}		

3.2 Worm gear load capacity rating criteria

The load capacity of a worm gear corresponds to the torque (or the power) which can be transmitted without the occurrence of tooth breakage or the appearance of excessive damage on the active flanks of the teeth during the design life of the gearing.

The following conditions can limit the rated load capacity:

— **wear:** damage usually appears on the tooth flanks of bronze worm wheels and is also influenced by the number of starts per hour,

— **pitting:** this form of damage may appear on the flanks of worm wheel teeth. Its development is strongly influenced by the load transmitted and the load-sharing conditions,

— **tooth breakage:** shear failure of worm wheel teeth or worm threads can occur when teeth become thin due to wear or overload,

— **worm thread and worm shaft breakage**: shaft breakage can occur as a result of bending fatigue or overload,

— **worm shaft deflection:** excessive deformation under load modifying contact pattern between worm and worm wheel,

— **scuffing:** this form of damage often appears suddenly. It is strongly influenced by transmitted load, sliding velocities and the conditions of lubrication,

— **working temperature:** when excessively high working temperature leads to accelerated degradation of the worm gear lubricant,

— **type of limitations in worm gear rating:** Table 2 indicates the relationship between different forms of capacity limits in combination with speed and torque.

When the many influence factors such as material properties, meshing conditions, (e.g. contact pattern under load), lubrication and etc. are considered, it is apparent that values of Hertzian pressure along the lines of contact are extremely significant.

The different rating criteria are calculated independently and not in combination (see Figure 1). For a given worm gear pair, the zone of contact could change with loading. At a steady load, fatigue pits can develop which may subsequently be reduced by wear. This can be followed by further pitting, additional wear or a stable condition.

The most significant factors of gear tooth damage, are shown in the first column of Table 2.

The load capacity of worm gearing is determined by calculations dealing with permissible stresses for pitting and wear, the deflection in worm, shafts, and the temperature. The permissible torque shall be determined from the least of the calculated values.

Table 2 — Most significant factors: failure mode according to influence factors

Influence factors	Failure modes					
	Wear	Pitting	Tooth-Breakage	Worm shaft Deflection	Scuffing	Low efficiency
Hertzian pressure	x	x	x	x	x	x
Worm speed	x	x			x	x
Oil film thickness	x	x			x	x
Oil	x	x			x	x
Contact Pattern	x	x	x		x	x
Worm surface roughness	x	x			x	x
Shearing value			x			

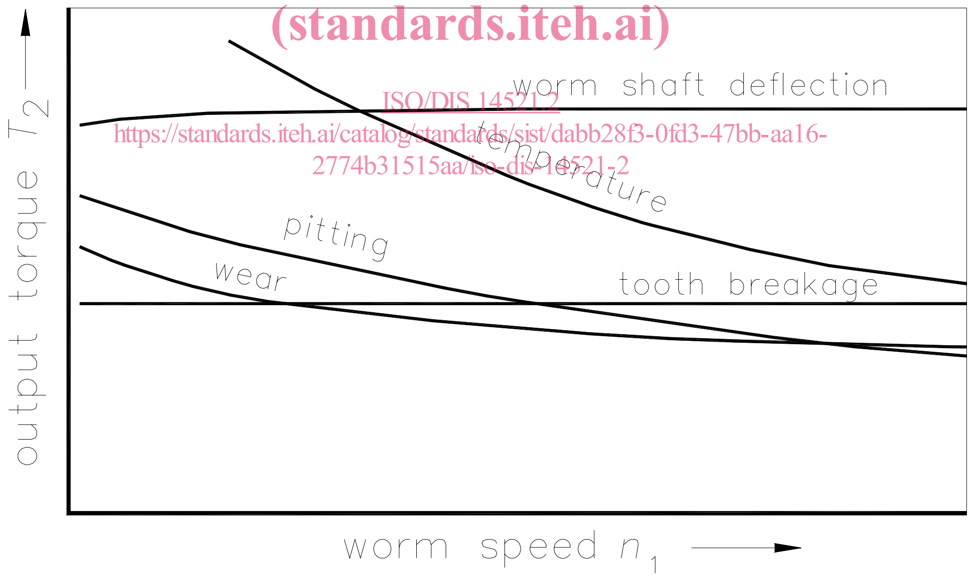

Figure 1a — Example for small center distance