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ISO 6336-6

Second edition
2019-11

Calculation of load capacity of spur and helical gears —

Part 6:
Calculation of service life under variable load

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

Partie 6: Calcul de la durée de vie en service sous charge variable

Reference number
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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).

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 2, *Gear capacity calculation*.

This second edition cancels and replaces the first edition (ISO 6336-6:2006), which has been technically revised. It also incorporates the Technical Corrigendum ISO 6336-6:2006/Cor.1:2007.

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

— in Annex A, examples have been revised;

— integration of Annex B "Equivalent cumulative damage".

A list of all parts in the ISO 6336 series can be found on the ISO website.

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

ISO 6336 (all parts) 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.

— Technical Specifications (TS) contain calculation methods that are still subject to further development.

— Technical Reports (TR) contain data that is informative, such as example calculations.

The procedures specified in parts 1 to 19 of the ISO 6336 series cover fatigue analyses for gear rating. The procedures described in parts 20 to 29 of the ISO 6336 series are predominantly related to the tribological behavior of the lubricated flank surface contact. Parts 30 to 39 of the ISO 6336 series 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 the ISO 6336 series 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 the ISO 6336 series need to be specified. Use of a Technical Specification as acceptance criteria for a specific design need to be agreed in advance between the manufacturer and the purchaser.

Table 1 — Parts of the ISO 6336 series (STATUS AS OF DATE OF PUBLICATION)

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 6336-1, 2, 3, 5			X
Part 31: Calculation examples of micropitting load capacity *(replaces: ISO/TR 15144-2)*			X

Calculation of load capacity of spur and helical gears —

Part 6:
Calculation of service life under variable load

1 Scope

This document specifies the information and standardized conditions necessary for the calculation of the service life (or safety factors for a required life) of gears subject to variable loading for only pitting and tooth root bending strength.

If this scope does not apply, refer ISO 6336-1:2019, Clause 4.

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

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)*

ISO 6336-3, *Calculation of load capacity of spur and helical gears — Part 3: Calculation of tooth bending strength*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6336-1 and ISO 1122-1:1998 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.2 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in ISO 6336-1, ISO 1122-1:1998 and Table 2 apply.

Table 2 — Symbols and abbreviated terms used in this document

Abbreviated terms

Term	Description
Eh	material designation for case-hardened wrought steel
GG	material designation for grey cast iron
GGG	material designation for nodular cast iron (perlitic, bainitic, ferritic structure)
GTS	material designation for black malleable cast iron (perlitic structure)
IF	material designation for flame or induction hardened wrought special steel
NT	material designation for nitrided wrought steel, nitriding steel
NV	material designation for through-hardened wrought steel, nitrided, nitrocarburized
St	material designation for normalized base steel (σ_B < 800 N/mm^2)
V	material designation for through-hardened wrought special steel, alloy or carbon ($\sigma_B \geq$ 800 N/mm^2)

Symbols

Symbol	Description	Unit
a	centre distance[a]	mm
b	face width	mm
d	diameter (without subscript, reference diameter[a])	mm
d_a	tip diameter[a]	mm
F	force or load	N
F_t	(nominal) transverse tangential load at reference cylinder per mesh	N
K	constant, factors concerning tooth load	—
K_A	application factor (Annex A shall apply for pitting and tooth root bending)	—
$K_{F\alpha}$	transverse load factor (bending)	—
$K_{F\beta}$	face load factor (bending)	—
$K_{H\alpha}$	transverse load factor (contact stress)	—
$K_{H\beta}$	face load factor (contact stress)	—
K_γ	mesh load factor	—
K_v	dynamic factor	—
m_n	normal module	mm
N	number of load cycles	—
N_i	number of load cycles to failure for bin i	—
N_L	number of load cycles of S-N curve	—
N_{LF}	number of load cycles for bending damage	—

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
N_{LH}	number of load cycles for pitting damage	—
$N_{L\,ref}$	number of load cycles for endurance limit	—
$n_{D,i}$	number of load cycles for the equivalent damage fatigue curve (Annex B)	—
$n_{D,REF}$	number of load cycles for the equivalent damage fatigue curve (reference) (Annex B)	—
$n_{eq,i}$	equivalent number of load cycles (Annex B)	—
$n_{eq,3REF}$	equivalent number of load cycles (reference) (Annex B)	—
n_i	number of load cycles for bin *i*	—
n_{Hi}	number of load cycles for contact stress for bin *i*	—
n_{Fi}	number of load cycles for tooth root stress for bin *i*	—
$n_{nom,i}$	number of load cycles for nominal stress in bin *i* (Annex B)	—
p	slope of the S-N curve	—
S	safety factor	—
S_F	safety factor for bending	—
S_H	safety factor for pitting	—
T	torque (pinion torque unless specified otherwise)	N·m
T_{eq}	equivalent torque	N·m
T_i	torque for bin *i*	N·m
T_n	nominal torque	N·m
U	sum of individual damage parts	—
U_i	individual damage parts for bin *i*	—
u	gear ratio $(\|z_2 / z_1\|) \geq 1$[a]	—
x	profile shift coefficient	—
Y	factor related to tooth root bending	—
Y_B	rim thickness factor	—
Y_{DT}	deep tooth factor	—
Y_F	tooth form factor, for the influence on nominal tooth root stress with load applied at the outer point of single pair tooth contact	—
Y_{NT}	life factor for tooth root stress for reference test conditions	—
$Y_{R\,rel\,T}$	relative surface factor, the quotient of the gear tooth root surface factor of interest divided by the tooth root surface factor of the reference test gear, $Y_{R\,rel\,T} = Y_R/Y_{RT}$	—
Y_S	stress correction factor, for the conversion of the nominal tooth root stress, determined for application of load at the outer point of single pair tooth contact, to the local tooth root stress	—

[a] For external gears *a*, *d*, d_a, z_1 and z_2 are positive; for internal gearing, *a*, *d*, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
Y_{ST}	stress correction factor, relevant to the dimensions of the standard reference test gears	—
Y_β	helix angle factor (tooth root)	—
$Y_{\delta\ rel\ T}$	relative notch sensitivity factor, the quotient of the gear notch sensitivity factor of interest divided by the standard reference test gear factor, $Y_{\delta\ rel\ T} = Y_\delta / Y_{\delta T}$	—
Z	factor related to contact stress	—
Z_B, Z_D	single pair tooth contact factors for the pinion, for the wheel	—
Z_E	elasticity factor	$(N/mm^2)^{0,5}$
Z_H	zone factor	—
Z_L	lubricant factor	—
Z_N	life factor for contact stress	—
Z_{NT}	life factor for contact stress for reference test conditions	—
Z_R	roughness factor affecting surface durability	—
Z_v	velocity factor	—
Z_W	work hardening factor	—
Z_X	size factor (pitting)	—
Z_β	helix angle factor (pitting)	—
Z_ε	contact ratio factor (pitting)	—
z	number of teeth[a]	—
z_n	virtual number of teeth of a helical gear	—
α	pressure angle (without subscript, at reference cylinder)	°
β	helix angle (without subscript, at reference cylinder)	°
σ	normal stress	N/mm^2
σ_D	stress value used to describe the equivalent damage fatigue curve (Annex B)	N/mm^2
σ_F	tooth root stress	N/mm^2
σ_{FG}	tooth root stress limit	N/mm^2
σ_{Fi}	tooth root stress for bin *i*	N/mm^2
σ_{FP}	permissible bending stress	N/mm^2
$\sigma_{F\ lim}$	nominal stress number (bending)	N/mm^2
σ_G	stress value used to describe the permissible S-N curve	N/mm^2
σ_H	contact stress	N/mm^2
σ_{HG}	pitting stress limit	N/mm^2
σ_{Hi}	contact stress for bin *i*	N/mm^2

[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.

Table 2 *(continued)*

Symbols		
Symbol	**Description**	**Unit**
σ_{HP}	permissible contact stress	N/mm^2
σ_P	stress value used to describe the S-N curve (Annex B)	N/mm^2
σ_{REF}	reference permissible stress level	N/mm^2
σ_i	stress for bin i	N/mm^2
$\sigma_{nom,i}$	nominal stress for bin i (Annex B)	N/mm^2
[a] For external gears a, d, d_a, z_1 and z_2 are positive; for internal gearing, a, d, d_a and z_2 have a negative sign, z_1 has a positive sign. All calculated diameters have a negative sign for internal gearing.		

4 General

4.1 Determination of load and stress spectra

Variable loads resulting from a working process, starting process or from operation at or near a critical speed will cause varying stresses at the gear teeth of a drive system. The magnitude and frequency of these loads depend upon the driven machine(s), the driver(s) or motor(s) and the dynamic mass elastic properties of the system.

These variable loads (stresses) may be determined by such procedures as

— experimental measurement of the operating loads at the machine in question,

— estimation of the spectrum, if this is known, for a similar machine with a similar operating mode, and

— calculation, using known external excitation and a mass elastic simulation of the drive system, preferably followed by experimental testing to validate the calculation.

To obtain the load spectra for fatigue damage calculation, the range of the measured (or calculated) loads is divided into bins or classes. Each bin contains the number of load occurrences recorded in its load range. A widely-used number of bins is 64. These bins can be of an equal size, but it is usually better to use larger bin sizes at the lower loads and smaller bin sizes at the upper loads in the range. In this way, the most damaging loads may be limited to fewer calculated stress cycles and the resulting design is more accurate regarding the effective load. It is recommended that a zero-load bin be included so that the total time used to rate the gears matches the design operating life. For consistency, the usual presentation method is to have the highest torque associated with the lowest numbered bins, such that the most damaging conditions appear towards the top of any table.

The cycle count for the load class corresponding to the load value for the highest loaded tooth is incremented at every load repetition. Table 3 shows as an example of how the torque classes defined in Table 4 can be applied to specific torque levels and correlated numbers of cycles.

Table 3 — Torque classes/numbers of cycles — Example: classes 38 and 39 (see Table 4)

Torque class, T_i N·m	**Number of cycles, n_i**
$11\,620 \le T_{38} \le 12\,619$	$n_{38} = 237$
$10\,565 \le T_{39} \le 11\,619$	$n_{39} = 252$

The torques used to evaluate the tooth loading should include the dynamic effects at different rotational speeds.

This spectrum is only valid for the measured or evaluated time period. If the spectrum is extrapolated to represent the required lifetime, the possibility that there might be torque peaks not frequent enough to be evaluated in that measured spectrum shall be considered. These transient peaks can have an effect on the gear life. Therefore, the evaluated time period could have to be extended to capture extreme load peaks.

Stress spectra concerning bending and pitting can be obtained from the load (torque).

The tooth root stress may also be measured by means of strain gauges in the fillet. The relevant contact stress may be calculated from the measurements.

Table 4 — Example of torque spectrum (with unequal bin sizes for a reducing number of bins) (see Annex C)

Data	Pinion			%	Time	
	Torque N·m		Load cycles			
Bin no.	minimum	maximum			s	h
1	25 502	25 578	0	0,00	0	0
2	25 424	25 501	0	0,00	0	0
3	25 347	25 423	14	0,37	24	0,006 7
4	25 269	25 346	8	0,21	14	0,003 9
5	25 192	25 268	5	0,13	9	0,002 5
6	25 114	25 191	8	0,21	14	0,003 9
7	25 029	25 113	16	0,42	28	0,007 8
8	24 936	25 028	8	0,21	14	0,003 9
9	24 835	24 935	5	0,13	9	0,002 5
10	24 727	24 834	11	0,29	19	0,005 3
11	24 610	24 726	16	0,42	28	0,007 8
12	24 479	24 609	19	0,50	33	0,009 2
13	24 331	24 478	14	0,37	24	0,006 7
14	24 168	24 330	14	0,37	24	0,006 7
15	23 990	24 168	11	0,29	19	0,005 3
16	23 796	23 989	15	0,39	26	0,007 2
17	23 579	23 796	31	0,81	52	0,014 4
18	23 339	23 579	28	0,73	47	0,013 1
19	23 076	23 338	36	0,94	62	0,017 2
20	22 789	23 075	52	1,36	88	0,024 4
21	22 479	22 788	39	1,02	66	0,018 3
22	22 138	22 478	96	2,51	163	0,045 3
23	21 766	22 137	106	2,77	180	0,050 0
24	21 363	21 765	49	1,28	83	0,023 1
25	20 929	21 362	117	3,05	200	0,055 6
26	20 463	20 928	124	3,24	212	0,058 9
27	19 960	20 463	61	1,59	104	0,028 9
28	19 417	19 959	140	3,65	238	0,066 1
29	18 836	19 416	148	3,86	253	0,070 3
30	18 216	18 835	117	3,05	200	0,055 6
31	17 557	18 215	121	3,16	206	0,057 2
32	16 851	17 556	174	4,46	297	0,082 5
33	16 100	16 851	185	4,83	316	0,087 8
34	15 301	16 099	196	5,11	334	0,092 8

Table 4 *(continued)*

Data	Pinion			%	Time	
	Torque N·m		Load cycles			
Bin no.	minimum	maximum			s	h
35	14 456	15 301	207	5,40	352	0,097 8
36	13 565	14 456	161	4,20	274	0,076 1
37	12 620	13 564	168	4,38	286	0,079 4
38	11 620	12 619	237	6,18	404	0,112 2
39	10 565	11 619	252	6,58	429	0,119 2
40	9 457	10 565	263	6,86	449	0,124 7
41	8 294	9 456	275	7,18	468	0,130 0
42	7 070	8 294	178	4,65	303	0,084 2
43	5 783	7 069	103	2,69	176	0,048 9
44	4 434	5 782	7	0,18	12	0,003 3
45	3 024	4 434	0	0,00	0	0
46	1 551	3 023	0	0,00	0	0
47	1	1 550	0	0,00	0	0
48	0	0	0	0,00	6 041 469	1 678,2
		Total ≥	3 832	100,0	6 048 000	1 680

4.2 General calculation of service life

The calculated service life is based on the theory that every load cycle (every revolution) is damaging to the gear. The amount of damage depends on the stress level and can be considered as zero for lower stress levels.

The calculated bending or pitting fatigue life of a gear is a measure of its ability to accumulate discrete damage until failure occurs.

The fatigue life calculation requires

a) the stress spectrum,

b) material fatigue properties, and

c) a damage accumulation method.

The stress spectrum is discussed in 5.1.

Strength values based on material fatigue properties are chosen from applicable S-N curves. Many specimens shall be tested by stressing them repeatedly at one stress level until failure occurs. This gives, after a statistical interpretation for a specific probability, a failure cycle number characteristic of this stress level. Repeating the procedure at different stress levels leads to an S-N curve.

An example of a cumulative stress spectrum is given in Figure 1. Figure 2 shows a cumulative contact stress spectrum with an S-N curve for specific material fatigue properties.