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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

DRAFT INTERNATIONAL STANDARD

IEC/DIS 61400-4

ISO/TC 60

Secretariat: ANSI

Voting begins on:
2023-09-22

Voting terminates on:
2023-12-15

Wind energy generation systems —

Part 4: Design requirements for wind turbine gearboxes

ICS: 27.180; 21.200

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This document is circulated as received from the committee secretariat.

This draft is submitted to a parallel vote in ISO and in IEC.



Reference number
IEC/DIS 61400-4:2023(E)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –

Part 4: Design requirements for wind turbine gearboxes

FOREWORD

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International Standard IEC 61400-4 has been prepared by IEC technical committee 88: Wind energy generation systems, in co-operation with ISO technical committee 60: Gears.

It is published as a double logo standard.

This second edition cancels and replaces IEC 61400-4 ed.1 published in 2012. It constitutes a technical revision of IEC 61400-4 ed.1 with extended content and changes in all pertinent sections.

This edition includes the following significant technical changes with respect to the previous edition:

- a) extension of the scope to wind turbines above 2 MW reference power;
- b) considerations for converging differing approaches to reliability in gear, bearing and wind turbine standards;
- c) a new clause on wind turbine loads specific to drivetrains;
- d) revised clause on verification and validation;

- e) new clause on design requirements for plain bearings
- f) expanded design considerations on the use of bearings based on avoiding standard failures;
- g) a revised clause on considerations and requirements in the design and analysis of gearbox structural elements;
- h) updated considerations and requirements on lubricants and lubrication systems;
- i) removal of requirements for documenting the compliance of a design with the requirements of the standard in favour of reference to IECRE OD-501-2

The text of this standard is based on the following documents of IEC:

FDIS	Report on voting
88/XXXX/FDIS	88/XXXX/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table. In ISO, the standard has been approved by 11 P-members out of 12 having cast a vote.

In addition, IEC TS 61400-4-1 has been issued in parallel with this edition of the standard. This Technical Specification describes requirements and recommendations for a unified and standardized method for reliability assessment of drivetrain components in wind turbines. The subject of reliability assessment is still under development and could therefore not achieve consensus for approval of an International Standard.

Parts of IEC 61400-4 ed.1 have been transferred into Technical Reports, with updates and amendments of the content:

- IEC TR 61400-4-2 provides additional information on lubrication of drivetrain components in wind turbines.
- IEC TR 61400-4-3 contains explanatory notes on the content of this standard, as well as supportive information for wind turbine gearbox design.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual edition of this document may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

IEC 61400-4 outlines minimum requirements for specification, design, and verification of gearboxes in wind turbines. It does not serve as a complete design specification or instruction manual. It is intended for use by experienced designers of wind turbine drivetrains, gearboxes, and gears or bearings who are capable of selecting reasonable values for the design factors, based on knowledge of similar designs and the effects of such items as lubrication, deflection, manufacturing tolerances, metallurgy, residual stress, and system dynamics.

Any of the requirements of this standard may be altered:

- if more accurate data are available from full scale load tests, precise measurements, comprehensive mathematical analysis, or any combination of these;
- or on the basis of proven operating experience;
- or the evidence is accessible for independent assessment (e.g. by an accredited renewable energy certification body);

and the accuracy and reliability of the alternative method is demonstrated with respect to the safety and reliability of the complete wind turbine drive system.

WIND ENERGY GENERATION SYSTEMS –

Part 4: Design requirements for wind turbine gearboxes

1 Scope

This part of the IEC 61400 series is applicable to enclosed speed increasing gearboxes for horizontal axis wind turbine drivetrains with a power rating in excess of 500 kW. This standard applies to newly designed gearboxes for wind turbines installed onshore or offshore. The technical requirements given in this standard are not intended for repaired or refurbished gearboxes, or for the extension of the service life beyond the design life.

This International Standard provides requirements and guidance on the analysis of the wind turbine loads in relation to the design of the gear and gearbox elements. The gearing elements covered by this standard include such gears as spur, helical or double helical and their combinations in parallel and epicyclic arrangements in the main power path. This standard does not apply to power take off (PTO) gears.

This standard includes requirements, design recommendations, and rating of gearboxes with rolling bearings, plain bearings, or combinations of both bearing types.

Also included are requirements and guidance on the engineering of shafts, shaft hub interfaces, lubrication, wind turbine controller interface, and the gear case structure to accomplish a design that is capable to withstand the environment and operating conditions of a wind turbine. Requirements for dynamic analysis of the gearbox within the wind turbine system are specified for the purpose of identifying load levels exceeding the predictions of the global aeroelastic simulation. The analysis of noise transmission and emission (e.g. tonal emission at gear mesh frequencies) is not within the scope of this document.

Further, this International Standard provides requirements and guidance on gearbox design verification, prototype testing and production testing, as well as consideration of design for service and maintenance.

Requirements and guidance for a systematic assessment of the design reliability of a gearbox design under reference operating conditions are given in IEC/TS 61400-4-1.

This International Standard is supported by two Technical Reports: IEC/TR 61400-4-2 provides additional information on lubrication of wind turbine drivetrains and IEC/TR 61400-4-3 contains explanatory notes and supportive information to the requirements specified in this standard.

The standard is written with conformity assessment and certification of the wind turbine in accordance with IECRE OD-501 in mind. The specific requirements for documenting conformity of a gearbox design with the technical requirements of this International Standard are described in IECRE OD-501-2.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- 60 IEC 60050 (all parts), *International Electrotechnical Vocabulary*
 61 Available at <<http://www.electropedia.org>>
- 62 IEC 61400-1, *Wind energy generation systems – Part 1: Design requirements*
- 63 IEC 61400-1:2019, *Wind energy generation systems – Part 1: Design requirements*
- 64 IEC 61400-3-1, *Wind energy generation systems – Part 3-1: Design requirements for fixed*
 65 *offshore wind turbines*
- 66 IEC/TS 61400-3-2, *Wind energy generation systems – Part 3-2: Design requirements for*
 67 *floating offshore wind turbines*
- 68 IEC 61400-8, *Wind energy generation systems – Part 8: Design of wind turbine structural*
 69 *components*
- 70 IEC/TS 61400-30, *Wind energy generation systems – Part 30: Safety of Wind Turbine*
 71 *Generator Systems (WTGs) – General principles for design*
- 72 ISO 281, *Rolling bearings – Dynamic load ratings and rating life*
- 73 ISO 683 (all parts), *Heat-treatable steels, alloy steels and free-cutting steels*
- 74 ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1:*
 75 *Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread*
- 76 ISO 898-2, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 2: Nuts with*
 77 *specified property classes – Coarse thread and fine pitch thread*
- 78 ISO 898-3, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 3: Flat*
 79 *washers with specified property classes*
- 80 ISO 1328-1, *Cylindrical gears – ISO system of accuracy – Part 1: Definitions and allowable*
 81 *values of deviations relevant to corresponding flanks of gear teeth*
- 82 ISO 3104, *Petroleum products – Transparent and opaque liquids – Determination of kinematic*
 83 *viscosity and calculation of dynamic viscosity*
- 84 ISO 4042, *Fasteners – Electroplated coating systems*
- 85 ISO 4406, *Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid*
 86 *particles*
- 87 ISO 6336-1:2019, *Calculation of load capacity of spur and helical gears – Part 1: Basic*
 88 *principles, introduction and general influence factors*
- 89 ISO 6336-2:2019, *Calculation of load capacity of spur and helical gears – Part 2: Calculation of*
 90 *surface durability (pitting)*
- 91 ISO 6336-3:2019, *Calculation of load capacity of spur and helical gears – Part 3: Calculation of*
 92 *tooth bending strength*
- 93 ISO/TS 6336-4, *Calculation of load capacity of spur and helical gears – Part 4: Calculation of*
 94 *tooth flank fracture load capacity*

- 95 ISO 6336-5, *Calculation of load capacity of spur and helical gears – Part 5: Strength and quality*
96 *of materials*
- 97 ISO 6336-5:2016, *Calculation of load capacity of spur and helical gears – Part 5: Strength and*
98 *quality of materials*
- 99 ISO 6336-6:2019, *Calculation of load capacity of spur and helical gears – Part 6: Calculation of*
100 *service life under variable load*
- 101 ISO/TS 6336-20, *Calculation of load capacity of spur and helical gears – Part 20: Calculation*
102 *of scuffing load capacity (also applicable to bevel and hypoid gears) – Flash temperature*
103 *method*
- 104 ISO/TS 6336-21, *Calculation of load capacity of spur and helical gears – Part 21: Calculation*
105 *of scuffing load capacity (also applicable to bevel and hypoid gears) – Integral temperature*
106 *method*
- 107 ISO/TS 6336-22, *Calculation of load capacity of spur and helical gears – Part 22: Calculation*
108 *of micropitting load capacity*
- 109 ISO/TS 6336-22:2018, *Calculation of load capacity of spur and helical gears – Part 22:*
110 *Calculation of micropitting load capacity*
- 111 ISO 6618, *Petroleum products and lubricants – Determination of acid or base number – Colour-*
112 *indicator titration method*
- 113 ISO 6619, *Petroleum products and lubricants – Neutralization number – Potentiometric titration*
114 *method*
- 115 ISO 7146-1, *Plain bearings – Appearance and characterization of damage to metallic*
116 *hydrodynamic bearings – Part 1: General*
- 117 ISO 8579-1, *Acceptance code for gear units – Part 1: test code for airborne sound*
- 118 ISO/TR 10064-3, *Cylindrical gears – Code of inspection practice – Part 3: Recommendations*
119 *relative to gear blanks, shaft centre distance and parallelism of axes*
- 120 ISO 10683, *Fasteners – Non-electrolytically applied zinc flake coating systems*
- 121 ISO 10825-1, *Gears – Wear and damage to gear teeth – Part 1: Nomenclature and*
122 *characteristics*
- 123 ISO 12925-1, *Lubricants, industrial oils and related products (class L). Family C (Gears) –*
124 *Part 1: Specifications for lubricants for enclosed gear systems*
- 125 ISO 14104, *Gears – Surface temper etch inspection after grinding*
- 126 ISO 14635-1, *Gears – FZG test procedures – Part 1: FZG test method A/8,3/90 for relative*
127 *scuffing load-carrying capacity of oils*
- 128 ISO 14635-1:2000, *Gears – FZG test procedures – Part 1: FZG test method A/8,3/90 for relative*
129 *scuffing load-carrying capacity of oils*
- 130 ISO 15243, *Rolling bearings – Damage and failures – Terms, characteristics and causes*
- 131 ISO 15243:2017, *Rolling bearings – Damage and failures – Terms, characteristics and causes*

- 132 ISO/TS 16281, *Rolling bearings – Methods for calculating the modified reference rating life for*
 133 *universally loaded bearings*
- 134 ISO 21920-1, *Geometrical product specifications (GPS) – Surface texture: Profile – Part 1:*
 135 *Indication of surface texture*
- 136 ISO 21920-2, *Geometrical product specifications (GPS) – Surface texture: Profile – Part 2:*
 137 *Terms, definitions and surface texture parameters*
- 138 ISO 21920-3, *Geometrical product specifications (GPS) – Surface texture: Profile – Part 3:*
 139 *Specification operators*
- 140 ANSI/AGMA 6001, *Design and selection of components for enclosed gear drives*
- 141 ANSI/AGMA 6123, *Design manual for enclosed epicyclic gear drives*
- 142 ASTM D445, *Standard test method for kinematic viscosity of transparent and opaque liquids*
 143 *(and calculation of dynamic viscosity)*
- 144 ASTM D664, *Standard test method for acid number of petroleum products by potentiometric*
 145 *titration*
- 146 ASTM D974, *Standard test method for acid and base number by color-indicator titration*
- 147 ASTM D5185, *Standard test method for multielement determination of used and unused*
 148 *lubricating oils and base oils by inductively coupled plasma atomic emission spectrometry (ICP-*
 149 *AES)*
- 150 ASTM D6304, *Standard test method for determination of water in petroleum products,*
 151 *lubricating oils, and additives by coulometric Karl Fischer titration*
- 152 DIN 471, *Circlips (retaining rings) for shafts: Normal type and heavy type*
- 153 DIN 472, *Circlips (retaining rings) for bores: Normal type and heavy type*
- 154 DIN 743, *Shafts and axles, calculations of load capacity, Parts 1, 2, 3*
- 155 DIN 3990-16, *Calculation of load capacity of cylindrical gears – Part 16: Determination of the*
 156 *micro-pitting load-carrying capacity of lubricants using FZG test method GT-C/8.3/90*
- 157 DIN 6885-1, *Drive type fastenings without taper action; Parallel keys, keyways, deep pattern*
- 158 DIN 6892, *Mitnehmerverbindungen ohne Anzug – Passfedern – Berechnung und Gestaltung*
 159 *(available in German only)*
- 160 DIN 7190, *Interference fits – Calculation and design rules*
- 161 DIN 51399-1, *Testing of lubricants – Determination of elements content in additives, wear and*
 162 *other contaminations – Part 1: Direct determination by optical emission spectral analysis with*
 163 *inductively coupled plasma (ICP OES)*
- 164 DIN 51777, *Petroleum products – Determination of water content using titration according to*
 165 *Karl Fischer*

DIN 51819-3, *Testing of lubricants – Mechanical-dynamic testing in the roller bearing test apparatus FE8 – Part 3: Test method for lubricating oils – Applied test bearing: axial cylindrical roller bearing*

FVA 563 I, *Standardization of load-bearing capacity tests*

VDI 2230-1, *Systematic calculation of highly stressed bolted joints – Joints with one cylindrical bolt*

VDI 2230-1:2015, *Systematic calculation of highly stressed bolted joints – Joints with one cylindrical bolt*

VDI 2230-2:2014, *Systematic calculation of highly stressed bolted joints – Multi bolted joints*

VDI/VDE 2862-2:2015, *Minimum requirements for application of fastening systems and tools – Applications in plant construction, mechanical engineering, equipment manufacturing and for flange connections in components under pressure boundary*

3 Terms, definitions, and conventions

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions 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

bearing reference load

load derived from the reference torque when translated to the desired load application point

3.1.2

bulk lubricant temperature

temperature of the lubricant that is representative of the overall volume of the lubricant within the lubrication system

3.1.3

design load

load value that the turbine and its components are designed to withstand

Note 1 to entry: Design loads are obtained by applying the appropriate partial load factors to the characteristic load in accordance with IEC 61400-1, IEC 61400-3-1, and IEC/TS 61400-3-2.

3.1.4

design validation

confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled

Note 1 to entry: See also IEC 60050 and Clause 8.

3.1.5**design verification**

confirmation, through the provision of objective evidence, that specified requirements have been fulfilled

Note 1 to entry: See also IEC 60050 and Clause 8.

3.1.6**equivalent load**

load which when repeated for a specified number of cycles causes the same damage as the actual load variation if a specified life exponent applies

Note 1 to entry: When applied to load ranges, the equivalent load does not take the mean-stress level of the load cycles into account.

3.1.7**excitability**

ability of a specific gearbox element to experience a forced vibration response due to the interaction of resonances and excitation sources

3.1.8**extreme load**

design load from any source, either operating or non-operating, that is the largest absolute value of the respective load component

Note 1 to entry: This component can be a force, a moment, a torque, or a combination of these.

3.1.9**interface**

boundary of the gearbox that is either a physical mount to another wind turbine subcomponent or a path of exchange such as control signals, hydraulic fluid, or lubricant

3.1.10**lubricant inlet temperature**

steady-state temperature of the lubricant where it enters the gearbox in pressure-fed or combined lubrication systems

3.1.11**maximum operating load**

highest load determined by the design load cases used in fatigue analysis including partial load safety factor as defined in IEC 61400-1, IEC 61400-3-1, and IEC/TS 61400-3-2.

3.1.12**model validation**

process of determining the degree to which the model is an accurate representation of corresponding physical experiments from the perspective of the intended uses of the model

Note 1 to entry: See ASME V&V 10.

3.1.13**model verification**

process of determining that a computational model accurately represents the underlying mathematical model and its solution

Note 1 to entry: See ASME V&V 10.

3.1.14**plain bearing hydrodynamic lubrication**

when the lubricant film thickness is greater than the minimum permissible lubricant film thickness for hydrodynamic lubrication, h_{lim}

3.1.15**plain bearing lubricant temperature**

temperature of the lubricant as measured in the vicinity of the contact

Note 1 to entry: This temperature can be significantly higher than the temperature of the lubricant supplied to the plain bearing.

Note 2 to entry: The accuracy of the plain bearing lubricant temperature measurement can be increased by making the measurement as close to the plain bearing contact surface as possible.

Note 3 to entry: This temperature is different from the temperature that is measured on the stationary ring of the plain bearing.

3.1.16**plain bearing mixed lubrication**

operation of a plain bearing with less than the minimum permissible lubricant film thickness

3.1.17**plain bearing starved lubrication**

operation of a plain bearing with a lubrication inlet flow rate below the required flow rate due to restricted or insufficient lubricant supply

3.1.18**rainflow matrices**

representation of fatigue loads using a two-dimensional matrix containing counts of cycle occurrence within sub-ranges of cyclic means and amplitudes

Note 1 to entry: See Annex A.

3.1.19**reference power**

arbitrarily chosen datum within the range of power set points of the wind turbine variants for which a gearbox type is designed

3.1.20**reference speed**

arbitrarily chosen datum within the range of rotor speed set points of the wind turbine variants for which a gearbox type is designed

3.1.21**reference torque**

torque value calculated from reference power and reference speed divided by the efficiency of the wind turbine, within the range of torque set points of the wind turbine variants for which a gearbox type is designed

3.1.22**rolling bearing lubricant temperature**

temperature of the lubricant as measured in the vicinity of the contact, typically the temperature of the lubricant supplied to the rolling bearing

Note 1 to entry: The accuracy of the rolling bearing lubricant temperature measurement is increased by making the measurement as close to the rolling elements as possible.

Note 2 to entry: This temperature is different from the bearing temperature that is measured on the stationary ring of a rolling bearing.

3.1.23**service life**

duration for which the gearbox performs its design function under actual operating conditions without unplanned costs for maintenance and repair

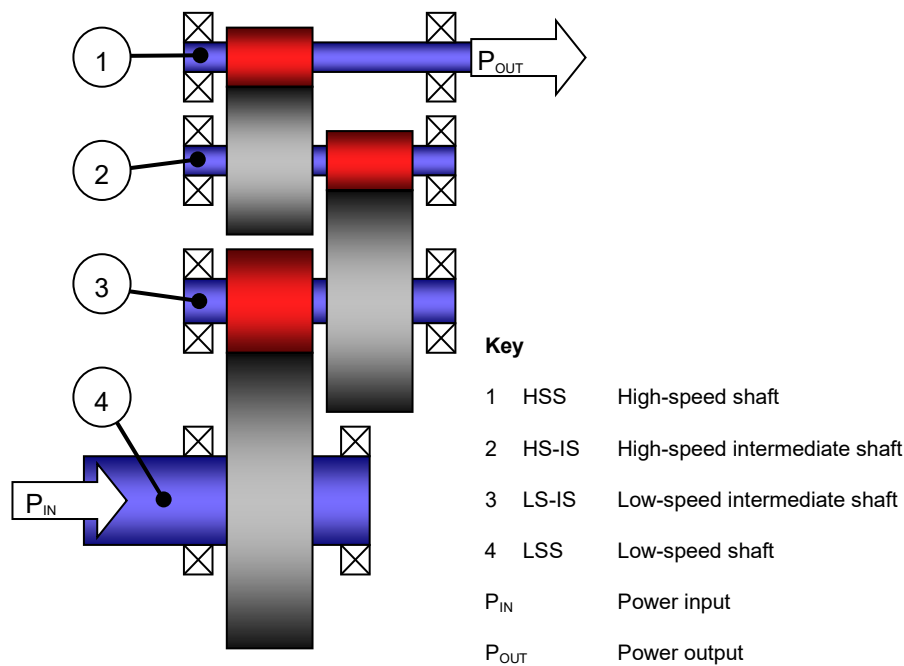
3.1.24**time series**

set of time sequences of loads, describing different operational regimes of the wind turbine

Note 1 to entry: These time series together with their corresponding occurrences specify the load history during the entire design life.

3.2 Conventions**3.2.1****shaft designations – examples for typical wind turbine gearbox architecture**

Figure 1 to Figure 4 show the designation of shafts in common 3-stage and 4-stage gearbox configurations.



IEC 2205/12

Figure 1 – Shaft designation in 3-stage parallel shaft gearboxes

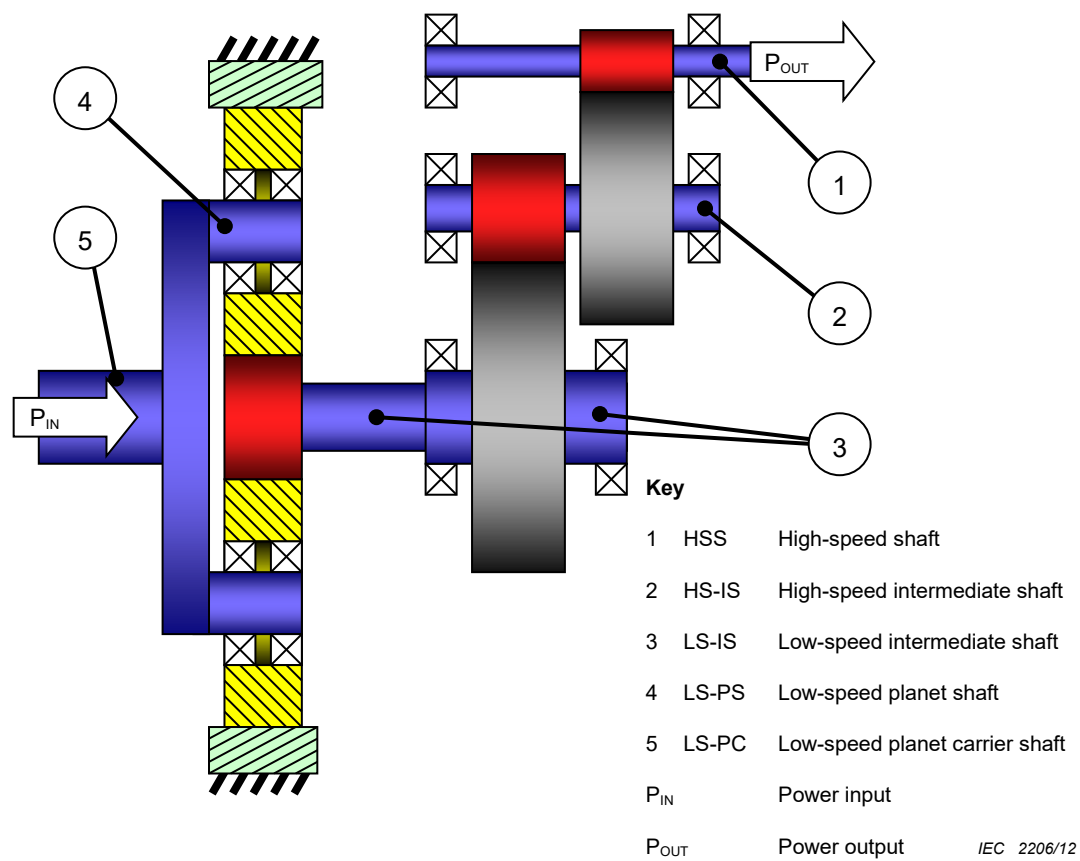


Figure 2 – Shaft designation in 3-stage gearboxes with one planet stage

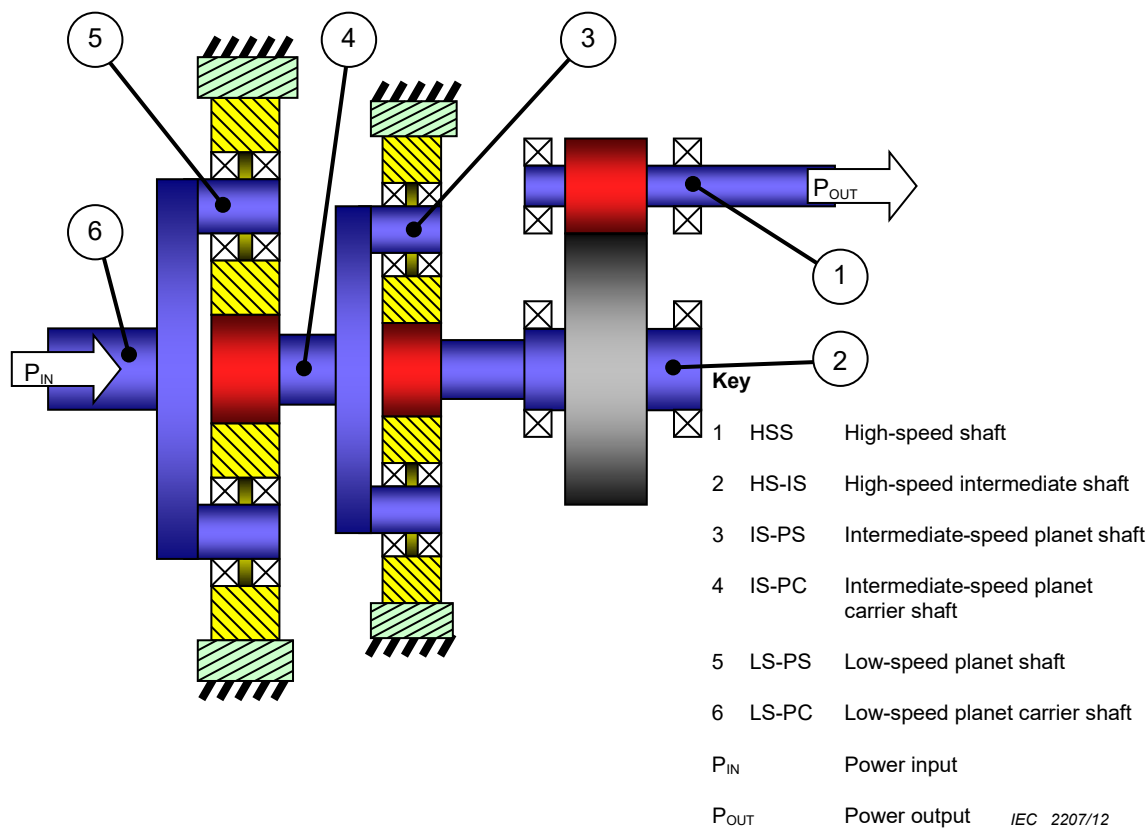


Figure 3 – Shaft designation in 3-stage gearboxes with two planet stages

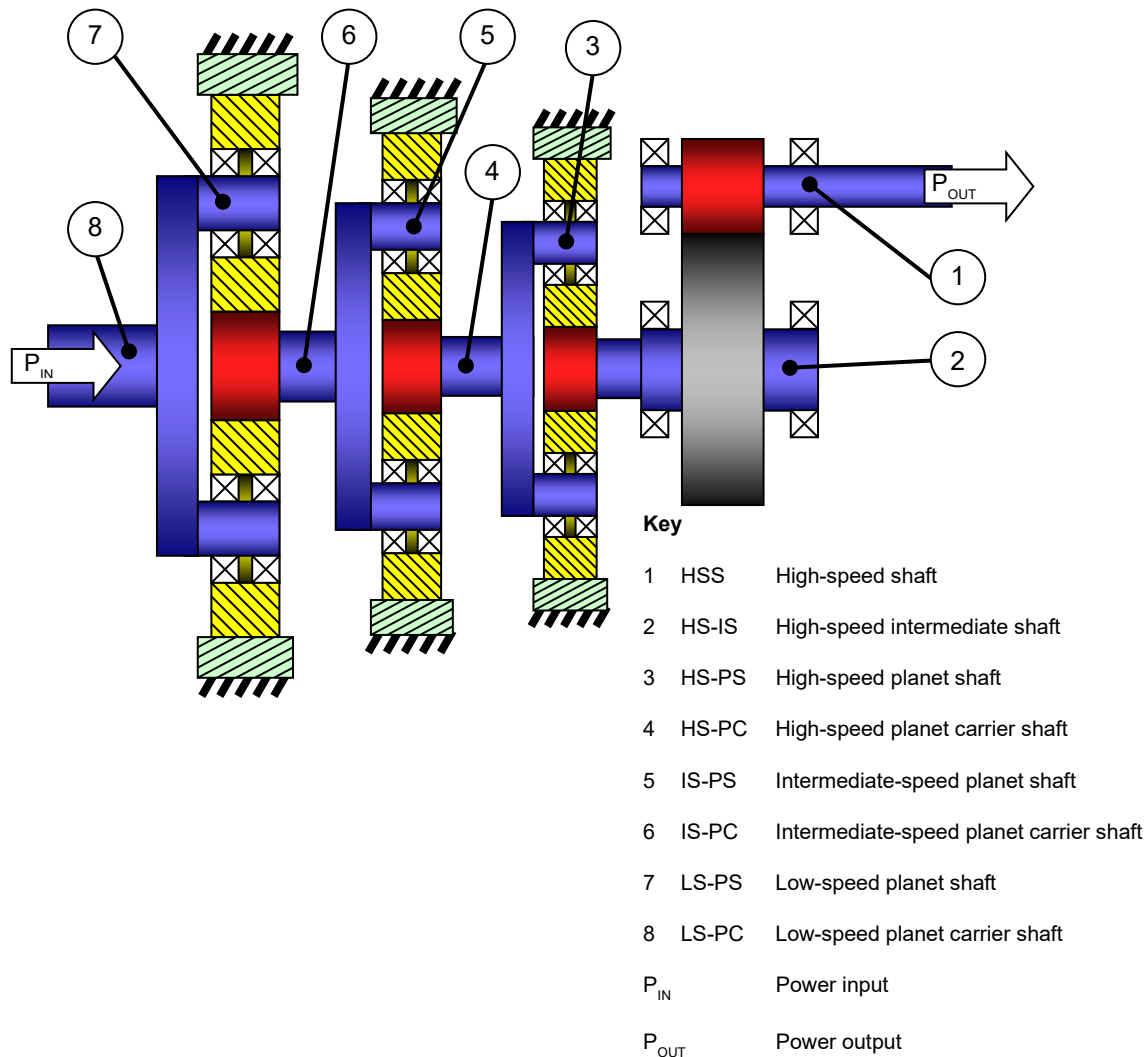


Figure 4 – Shaft designation in 4-stage gearboxes with three planet stages

4 Symbols, abbreviations, and units

4.1 Symbols and units

This standard uses equations and relationships from several engineering specialties. As a result there are, in some cases, conflicting definitions for the same symbol. All the symbols used in the document are nevertheless listed in Table 1, but, if there is ambiguity, the specific definition is presented in the clause where they are used in equations, graphs, or text.

Table 1 – Symbols used in the document

Symbol	Description	Unit
a_1	life adjustment factor for reliability	–
b_{PI}	planet wheel facewidth	mm
D_{pw}	working pitch diameter	mm
e_C	lubricant contamination factor	–
F	force	N
F_p	peak load factor	–

Symbol	Description	Unit
F_P	cumulative pitch deviation (index deviation), total	μm
F_r	runout	μm
$f_{H\beta 1}$	helix slope deviation of the pinion	mm
$f_{H\beta 2}$	helix slope deviation of the gear	mm
f_{ma}	mesh misalignment of a gear set installed in the housing	mm
f_ε	load distribution influence factor	–
$f_{\Sigma\delta}$	in-plane deviation of housing or carrier	mm
$f_{\Sigma\gamma}$	resulting mesh misalignment caused by deviations of the shaft alignment to the ideal axis projected into the face width	mm
$f_{\Sigma\beta}$	out-of-plane deviation of housing or carrier	mm
h_{lim}	minimum permissible lubricant film thickness for hydrodynamic lubrication	μm
K_A	application factor K_A (pitting)	–
$K_{F\alpha}$	transverse load factor (bending stress)	–
$K_{F\beta}$	face load factor (bending stress)	–
$K_{H\alpha}$	transverse load factor (contact stress)	–
$K_{H\beta}$	face load factor (contact stress)	–
K_v	dynamic factor	–
K_γ	mesh load factor	–
k_c	reliability factor	–
L_B	length of the bearing bore of a planet with shouldered cylindrical bores	mm
L_{ce}	distance between middle of the raceways	mm
L_i	mean load in the i^{th} bin	N or N·m
L_{nmr}	combined modified reference rating life at $(100 - n)$ % reliability	10^6 rev
L_{nr}	basic reference rating life at $(100 - n)$ % reliability	10^6 rev
$L_{Shoulder}$	length of the shoulder of a planet with shouldered cylindrical bores	mm
$L_{10mr,i}$	modified reference rating life at the i^{th} load level at 90 % reliability	10^6 rev
M	moment	N·m
m_n	normal module	mm
N_L	reference number of cycles	–
n	reliability expressed as a percentage of failure	%
n_i	speed at the i^{th} load level	–
n_{ij}	number of cycles in the i^{th} load level and j^{th} range level	–
n_R	shaft speed	1/min
q_i	portion of time at the i^{th} load level	–
R_a	arithmetic mean roughness	μm
R_j	j^{th} range level	–
R_{mr}	material ratio	%
R_q	root mean square deviation of the assessed shaft and plain bearing profiles	μm
R_z	mean peak-to-valley roughness	μm

Symbol	Description	Unit
S_B	safety factor for scuffing	–
S_F	safety factor for tooth breakage	–
S_H	safety factor for pitting	–
S_R	rim thickness of a planet with cylindrical bores	mm
S_{Ra}	rim thickness of a planet with shouldered cylindrical bores	mm
S_{Re}	rim thickness of a planet with tapered bores	mm
$S_{Shoulder}$	rim thickness of the shoulder of a planet with shouldered cylindrical bores	mm
S_0	(bearing) static safety factor	–
S_λ	safety factor against micropitting	–
Y_{NT}	life factor for tooth-root stress for reference test conditions	–
Y_{Sg}	stress correction factor for gears with notches in fillets	–
Y_β	helix angle factor (tooth root)	–
Z_{NT}	life factor for contact stress for reference test conditions	–
γ_f	partial safety factor for loads	–
γ_n	partial safety factor for consequence of failure	–
κ	viscosity ratio	–
λ	ratio of the film thickness to the composite surface finish	–
$\lambda_{GF,min}$	minimum specific lubricant film thickness	–
λ_{GFP}	permissible specific lubricant film thickness	–
σ	stress (true stress)	MPa
σ_H	contact stress	MPa

4.2 Abbreviations

Abbreviations are given in Table 2.

Table 2 – Abbreviations

Abbreviation	Description
AGMA	American Gear Manufacturers Association
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
DIN	Deutsches Institut für Normung
DLC	design load case
EP	extreme pressure
EXT	extreme load (matrices)
FAT	factory acceptance testing
FEA	finite element analysis
FMEA	failure mode and effects analysis
FVA	Forschungsvereinigung Antriebstechnik
FZG	“Forschungsstelle für Zahnräder und Getriebebau” TU Munich
GfT	Gesellschaft für Tribologie

Abbreviation	Description
GS	generator-side
HS-IS	high-speed intermediate shaft
HSS	high-speed shaft
IEC	International Electrotechnical Commission
IECRE	IEC system for certification to standards relating to equipment for use in renewable energy applications
ISO	International Organization for Standardization
IS-PS	intermediate-speed planet shaft
ISS	intermediate-speed shaft
LRD	load revolution distribution (histogram)
LS-IS	low-speed intermediate shaft
LS-PS	low-speed planet shaft (or axle)
LSS	low-speed shaft
PS	planet shaft (or axle)
PTO	power take-off, additional output shafts driving auxiliary equipment such as lubricant pumps
RFC	rainflow cycle count
RS	rotor-side
SPC	statistical process control
TFF	tooth flank fracture
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik
VDI	Verein Deutscher Ingenieure
WEC	white etching crack

323

324 5 Design process

325 5.1 General

326 The objective of the design of a wind turbine gearbox is to achieve high availability and a
 327 reliability that is sufficient to achieve predictable and affordable maintenance and repair cost
 328 throughout the design life.

329 5.2 Gearbox type

330 Most wind turbine types are offered in multiple variants to account for variations in application,
 331 operating conditions, wind regime, grid frequency, rotor diameters, or power ratings. Different
 332 gearbox variants can accommodate different demands, for example with respect to reference
 333 speed, gear ratio or reference torque. These gearbox variants are of the same gearbox type if
 334 all of the following criteria are fulfilled:

- 335 • all variants share the same design basis, use the same concepts and technologies, and
 336 share the same manufacturing processes;
- 337 • all design and operating parameters are within the ranges specified in Table 3, the design
 338 of the variant adheres to the minimum calculated safety factors and rating life requirements
 339 specified in Clause 7, and the risk assessment described in 5.5 does not indicate new failure
 340 modes.

341 Variants of the same gearbox type will typically share components or modules (e.g. a complete
 342 planetary stage). Variants within a gearbox type may be verified by similarity as described
 343 in 8.4.3 if at least one variant of the type is verified by testing in accordance with Clause 8.

344

Table 3 – Definition of a gearbox type

Commonalities within a gearbox type	Allowable difference to gearbox verified by testing
Reference speed of any gear stage	within –10 % to +5 %
Gearbox input reference torque	within –10 % to +5 %
Number of planet gears	for 4 to 5 planet gears: ± 1 for 6 or more planet gears: ± 2
Tooth width of any gear stage	within ± 10 %
Gear macrogeometry	contact stresses within –10 % to +5 % bending stresses within –20 % to +10 % specific sliding within ± 10 % mesh frequency within ± 10 %
Gear microgeometry	same type of modifications maximum local contact pressure within ± 10 %
Strength and quality of gear materials	same base material and equivalent heat treatment process (unless, for an alternative material of the same type and heat treatment method the strength is verified by material testing in accordance with 7.1.4)
strength and quality of materials for structural components	same base material and equivalent heat treatment process (unless, for an alternative material of the same type, heat treatment method and maximum ± 5 % difference in Young's modulus, strength is verified by material testing in accordance with 7.5)
Bearing arrangements	same arrangement and same bearing types
Rolling bearing dimensions	contact stress within ± 10 %
Plain bearing dimensions	minimum film thickness within –5 % to +20 % and mean contact pressure within –20 % to +5 %
Structural load path	same concept and dimensions of joints, flanges, etc.
Structural elements	stiffness with respect to load distribution of gears (7.1.3) and bearings (7.2.7 and 7.3.6) within ± 5 %
Gearbox mounting	same arrangement
Lubrication	flow rate within ± 5 % and filtration beta rate within ± 5 %
Lubricant type	same base oil type and same viscosity grade and viscosity index within ± 20 %

345

346 5.3 Design life, service life, and reliability

347 The design life of the gearbox should at least be the same as for the wind turbine. IEC 61400-1
 348 requires that the design life of a wind turbine for wind classes I to III is at least 20 years.
 349 IEC 61400-1, IEC 61400-3-1 and IEC/TS 61400-3-2 define additional wind classes that can
 350 have different design lifetimes. The loads compiled for this design life are used to design and
 351 rate the gearbox components according to specific design standards. These design standards
 352 (e.g. the ISO 6336 series or ISO 281) are written for general applications and do not stipulate
 353 safety factors or design life to meet the requirements for specific applications. They output
 354 results in different metrics, such as safety factors, rating life, and/or probabilities of failure.

355 The design reliability of the gearbox should be calculated from these metrics in accordance with
 356 IEC/TS 61400-4-1. IEC/TS 61400-4-1 calculates a design reliability for a limited number of
 357 failure modes where generally recognized calculation methods exist. For these failure modes,
 358 the method allows the comparison of design reliability between different gearbox designs or the
 359 comparison of different operating conditions on the reliability of the same gearbox design.

360 The current edition of IEC/TS 61400-4-1 does not cover all relevant failure modes in wind
 361 turbine gearboxes. It will therefore not predict the reliability in operation with confidence and
 362 should not yet be used to specify a system reliability target. It should also not yet be used to
 363 optimize system reliability because it will bias the design towards the calculable failure modes,
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with possibly detrimental effect on other failure modes (e.g. skidding of rolling bearings). Application of IEC/TS 61400-4-1 and comparison of the results with apparent failure probabilities in the field can deliver valuable information to complete and validate the method.

Scheduled maintenance and even scheduled (or preventive) replacement of components can increase the availability and reliability of the gearbox, or extend its remaining useful service life. Components with a design life less than that specified for the entire gearbox shall be serviceable or replaceable. Condition monitoring systems can further increase the availability as they can detect failures in due time to plan for repair.

5.4 Component class and consequence of failure

IEC 61400-1, IEC 61400-3-1 and IEC/TS 61400-3-2 define component classes as a function of the consequences of failure. The partial safety factor for consequences of failure, γ_n , for the gearbox components shall correspond to class 2 according to IEC 61400-1:2019. Class 3 according to IEC 61400-1:2019 can apply for some gearbox components if they support actuators, brakes, or blocking devices that are part of non-redundant wind turbine protection functions. Any class 3 gearbox components shall be documented.

5.5 Design process

Designing a drivetrain for a wind turbine is an iterative process that integrates input from many domains such as wind turbine design and control strategy, drivetrain concept, gearbox design, bearing concepts and design, or lubricant choice. Relevant parties should be included as early as possible in the design process. The design process flow chart shown in Figure 5 can be used as a starting point.

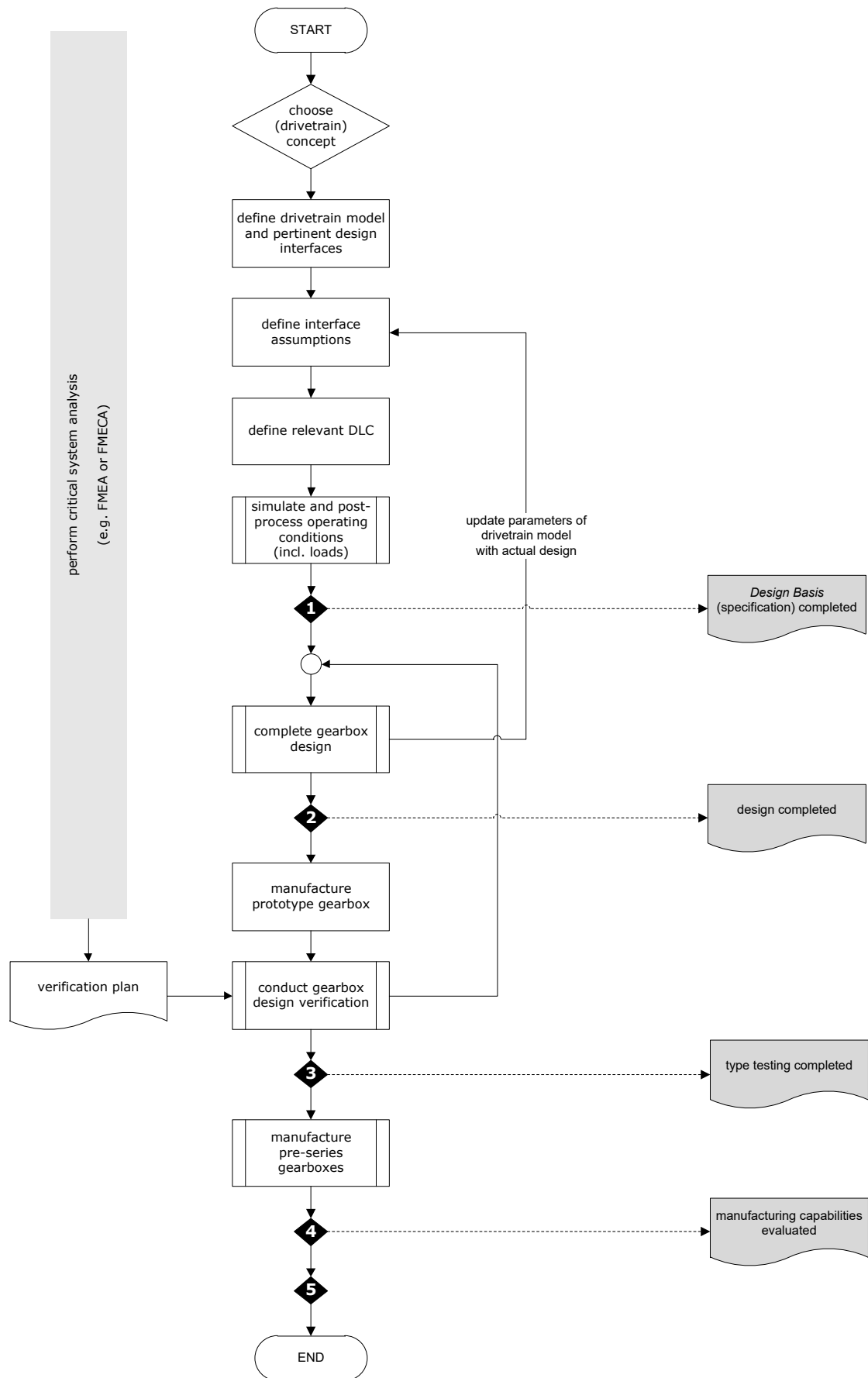


Figure 5 – Design process flow chart

During the entire design process, each group should concurrently be involved in a systematic and documented critical systems analysis, such as a failure mode and effects analysis (FMEA) or failure mode, effects, and criticality analysis, to identify design assumptions which strongly influence the correct design, manufacture, and operation of the gearbox. The system analysis should include:

- relevant design load cases;
- system architecture;
- interfaces;
- interface requirements;
- functional requirements for each element;
- potential failure modes;
- potential consequences of failure;
- limited life components;
- lubrication and cooling;
- manufacturing quality demands;
- service and maintenance;
- monitoring;
- transportation;
- installation;
- commissioning.

The first step of wind turbine design process includes selecting the rotor design, the drivetrain configuration, the torque and power-limiting methodology, and control system architecture. An initial analysis of the rotor and control design results in a first iteration of the gearbox concept, the design envelope and the operational characteristics including the system loads.

This gearbox concept forms the basis for establishing a model of the drivetrain including the relevant interfaces and interface assumptions as noted in Clause 6. Based on this description, relevant design load cases (DLCs) are defined per IEC 61400-1, IEC 61400-3-1 and IEC/TS 61400-3-2, and more detailed load calculations will be performed resulting in design loads at the defined interfaces. As the loading of the wind turbine is significantly influenced by the control and regulation systems, the impacts of control actions on loads are included in this analysis. The resulting design loads normally include time series simulations for many conditions. These can then be processed into extreme load tables, fatigue spectra in the form of rainflow matrices or load duration histograms, and other descriptions of operational characteristics (see Annex A). Specifying the design loads at the interfaces completes the Design Basis (as defined in IECRE OD-501) for the gearbox, indicated as milestone <1> in Figure 5.

With the loads and operational characteristics defined and specified, the initial gearbox design can take place. Because the actual design details of the gearbox affect turbine dynamics, reasonable estimates and assumptions are made for some of the motions, deflections, and other dynamic response at the interfaces. These could be derived, for instance, from previous wind turbine designs. Once verified values become available from more detailed design analysis and testing, they can be included in further simulations. Rating calculations and structural strength assessment as described in Clause 7 of this document conclude the design phase, as shown as milestone <2> in Figure 5.

The initial design results in one or more prototype gearboxes. The prototype design is verified at various levels as described in Clause 8. The verification plan described in Clause 8 is derived from the critical system analysis and based on the design loads as well as uncertainties in the design. Successful completion and documentation of the verification activities finalizes the type tests, indicated by milestone <3> in Figure 5. Missed verification objectives will require design

improvements, followed by partial repetition of the verification activities to demonstrate the effectiveness of the improvements. During the production ramp-up, capability and stability of all manufacturing and assembly steps as well as quality assurance procedures are established as described in Clause 9. This step includes the development of the specification for factory acceptance tests in serial production, based on the critical system analysis as well as design verification results as further specified in 9.5. Milestone <4> in Figure 5 includes the completion of preparations for serial production.

Milestone <5> in Figure 5 indicates an integrated design review that uses verification results, production experience, and any available field operation or test data to finally evaluate, verify, or possibly iterate the design.

6 Gearbox interfaces and loads

6.1 General

The IEC 61400 series define the design requirements for wind turbines including the design load cases for the different operating conditions for the entire design life as well as the environmental conditions for the site.

The gearbox external conditions and design situations shall be as defined in IEC 61400-1. Additional requirements for offshore applications shall be included according to IEC 61400-3-1 or IEC/TS 61400-3-2.

6.2 Interfaces

All interfaces between the gearbox and the wind turbine shall be defined. At a minimum, the following shall be specified for each interface:

- forces and moments acting on the interface;
- rotational speed;
- temperatures;
- voltage and currents for electrical devices such as pumps or heaters;
- lubricant flow, temperature, and pressures.

Interface specifications should also address potential undesired conditions that can occur in the interface, for example:

- misalignment or alignment tolerances;
- relative motions;
- accelerations;
- deflections;
- stray currents.

6.3 Loads

Gearbox loads shall be derived from wind turbine load calculations according to IEC 61400-1. Additional requirements for offshore applications shall be included according to IEC 61400-3-1 or IEC/TS 61400-3-2.

The external conditions and design situations of special interest to the gearbox should be identified and considered in the design:

- situations resulting in global gearbox motions;
- situations resulting in torque reversals;

- situations resulting from asymmetric and non-torque loading on the gearbox.

All loads used in the design of the gearbox shall be documented and, at a minimum include the following data:

- the coordinate system in which the loads are described;
- a description of the design load cases in accordance with IEC 61400-1, IEC 61400-3-1, or IEC/TS 61400-3-2, including extreme and fatigue loads;
- duration and frequency of occurrence;
- load revolution distribution (LRD) presenting the number of shaft revolutions at a certain torque level;
- contemporaneous loads associated with design driving extreme loads. The loads should be presented as described in IEC 61400-1:2019, Annex I;
- information on the time domain load simulation model including total gear ratio, inertia, and stiffness.

6.4 Drivetrain dynamics

6.4.1 Introduction

A drivetrain dynamic analysis shall be performed to assess the excitability of the gearbox within the operational speed range of the wind turbine system. The purpose of the analysis is the identification of load levels which exceed those predicted by the global aeroelastic model of the wind turbine.

The wind turbine system, including the gearbox and all drivetrain elements, is a dynamic system that can transmit and potentially amplify any excitation; both those created inside the gearbox or those generated by interfacing systems and transferred to the gearbox. The drivetrain analysis should have sufficient fidelity to capture higher frequency response (e.g. 350 Hz) because the frequencies at which excitability occurs can be significantly higher than the common resolution of global aeroelastic models. In a wind turbine operating at variable speed, these excitations occur over a broad range of frequencies.

6.4.2 Model requirements

A dynamic analysis model shall include mass, inertia, stiffness, and damping properties of at least the following elements:

- rotor blades and hub, representing all eigenmodes in edgewise direction up to at least 10 Hz;
- gearbox;
- generator, at least including rotor and stator frame including housing;
- main shaft, main bearing(s), and main bearing support structure;
- shaft couplings;
- brake disc;
- gearbox and generator mounts;
- simplified representation of main foundation and tower top, representing the contributions of the support structure on roll modes of the drivetrain around its longitudinal axis.

The gearbox shall be resolved into individual elements representing stiffness, mass, inertia, and damping values of gears, shafts, planet carriers, bearings, and housing. In particular, the linearized, radial stiffness of planet bearings shall be included in the model. Each element shall be discretized by at least two masses and one stiffness, except for planet gears which may be represented by one mass.