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Interested committees:

Title: Draft BS IEC 61400-4 Wind energy generation systems. Part 4: Design requirements for wind turbine gearboxes.

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
- iii) requires additional national guidance or information

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This draft is issued to allow comments from interested parties; all comments will be given consideration prior to publication. No acknowledgement will normally be sent. **See overleaf for information on the submission of comments.**

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Information on the co-operating organizations represented on the committees referenced above may be obtained from <https://standardsdevelopment.bsigroup.com/>.

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 Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.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	Commend (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.	



88/843/CD

COMMITTEE DRAFT (CD)

PROJECT NUMBER: IEC 61400-4 ED2	
DATE OF CIRCULATION: 2021-09-03	CLOSING DATE FOR COMMENTS: 2021-11-26
SUPERSEDES DOCUMENTS: 88/694/RR	

IEC TC 88 : WIND ENERGY GENERATION SYSTEMS	
SECRETARIAT: Denmark	SECRETARY: Mrs Christine Weibøl Bertelsen
OF INTEREST TO THE FOLLOWING COMMITTEES:	PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.
FUNCTIONS CONCERNED: ☐ EMC ☒ ENVIRONMENT ☒ QUALITY ASSURANCE ☒ SAFETY	

This document is still under study and subject to change. It should not be used for reference purposes.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

TITLE:

Wind energy generation systems – Part 4: Design requirements for wind turbine gearboxes

NOTE FROM TC/SC OFFICERS:

This project is developed by both IEC and ISO committees – As this work lies under JWG 1, Wind turbine gearboxes linked to ISO/TC 60, the document will be circulated in parallel in both IEC TC 88 and ISO TC 60.

In order to assist JWG 1 when sorting and compiling the given comments to the CD document, it is of great importance that all comments given in the comments form reference both to clause and line number in the CD document.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –

Part 4: Design requirements for wind turbine gearboxes

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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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) new clause on testing and validation of new gearbox designs;
- e) updated bearing selection tables for different locations in a wind turbine gearbox;
- f) new clause on design requirements for plain bearings
- g) expanded design considerations on the use of bearings based on avoiding standard failures;
- h) a new clause on considerations and requirements in the design and analysis of gearbox structural elements;
- i) updated considerations and requirements on lubricants and lubrication systems;
- j) 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/xxx/FDIS	88/xxx/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 will be issued. This Technical Specification proposes 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 further 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 is not intended for use as a complete design specification or instruction manual, and it is not intended to assure performance of assembled drive systems. It is intended for use by experienced gear designers capable of selecting reasonable 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. It is not intended for use by the engineering public at large.

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;
- on the basis of proven operating experience;
- the evidence is accessible for independent assessment (e.g. by an accredited RECB)

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

Also included is guidance on the engineering of shafts, shaft hub interfaces, bearings, lubrication, and the gear case structure in the development of a fully integrated design that meets the rigours of the operating conditions.

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.

Information on a systematic assessment of the design reliability of a gearbox design under reference operating conditions is 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.

- 57 IEC 60050 (all parts), *International Electrotechnical Vocabulary*
58 Available at <<http://www.electropedia.org>>
- 59 IEC 61400-1, *Wind energy generation systems – Part 1: Design requirements*
- 60 IEC 61400-1:2019, *Wind energy generation systems – Part 1: Design requirements*
- 61 IEC 61400-3-1, *Wind energy generation systems – Part 3-1: Design requirements for*
62 *fixed offshore wind turbines*
- 63 IEC/TS 61400-3-2, *Wind energy generation systems – Part 3-2: Design requirements for*
64 *floating offshore wind turbines*
- 65 IEC 61400-8, *Wind energy generation systems – Part 8: Design of wind turbine structural*
66 *components*
- 67 ISO 281, *Rolling bearings – Dynamic load ratings and rating life*
- 68 ISO 683 (all parts), *Heat-treatable steels, alloy steels and free-cutting steels*
- 69 ISO 1328-1, *Cylindrical gears – ISO system of accuracy – Part 1: Definitions and*
70 *allowable values of deviations relevant to corresponding flanks of gear teeth*
- 71 ISO 3104, *Petroleum products – Transparent and opaque liquids – Determination of*
72 *kinematic viscosity and calculation of dynamic viscosity*
- 73 ISO 4406, *Hydraulic fluid power – Fluids – Method for coding the level of contamination*
74 *by solid particles*
- 75 ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results –*
76 *Part 2: Basic methods for the determination of repeatability and reproducibility of a*
77 *standard measurement method*
- 78 ISO 6336-1, *Calculation of load capacity of spur and helical gears – Part 1: Basic*
79 *principles, introduction and general influence factors*
- 80 ISO 6336-1:2019, *Calculation of load capacity of spur and helical gears – Part 1: Basic*
81 *principles, introduction and general influence factors*
- 82 ISO 6336-2, *Calculation of load capacity of spur and helical gears – Part 2: Calculation*
83 *of surface durability (pitting)*
- 84 ISO 6336-2:2019, *Calculation of load capacity of spur and helical gears – Part 2:*
85 *Calculation of surface durability (pitting)*
- 86 ISO 6336-3, *Calculation of load capacity of spur and helical gears – Part 3: Calculation*
87 *of tooth bending strength*
- 88 ISO 6336-3:2019, *Calculation of load capacity of spur and helical gears – Part 3:*
89 *Calculation of tooth bending strength*
- 90 ISO 6336-5, *Calculation of load capacity of spur and helical gears – Part 5: Strength and*
91 *quality of materials*

- 92 ISO 6336-5:2016, *Calculation of load capacity of spur and helical gears – Part 5: Strength*
93 *and quality of materials*
- 94 ISO 6336-6, *Calculation of load capacity of spur and helical gears – Part 6: Calculation*
95 *of service life under variable load*
- 96 ISO 6336-6:2019, *Calculation of load capacity of spur and helical gears – Part 6:*
97 *Calculation of service life under variable load*
- 98 ISO/TS 6336-20, *Calculation of load capacity of spur and helical gears – Part 20:*
99 *Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) – Flash*
100 *temperature method*
- 101 ISO/TS 6336-21, *Calculation of load capacity of spur and helical gears – Part 21:*
102 *Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) – Integral*
103 *temperature method*
- 104 ISO/TS 6336-22, *Calculation of load capacity of spur and helical gears – Part 22:*
105 *Calculation of micropitting load capacity*
- 106 ISO/TS 6336-22:2018, *Calculation of load capacity of spur and helical gears – Part 22:*
107 *Calculation of micropitting load capacity*
- 108 ISO 6618, *Petroleum products and lubricants – Determination of acid or base number –*
109 *Colour-indicator titration method*
- 110 ISO 6619, *Petroleum products and lubricants – Neutralization number – Potentiometric*
111 *titration method*
- 112 ISO 7146-1, *Plain bearings – Appearance and characterization of damage to metallic*
113 *hydrodynamic bearings – Part 1: General*
- 114 ISO 8579-1, *Acceptance code for gear units – Part 1: test code for airborne sound*
- 115 ISO/TR 10064-3, *Cylindrical gears – Code of inspection practice – Part 3:*
116 *Recommendations relative to gear blanks, shaft centre distance and parallelism of axes*
- 117 ISO 10825, *Gears – Wear and damage to gear teeth – Terminology*
- 118 ISO 12925-1, *Lubricants, industrial oils and related products (class L). Family C (Gears)*
119 *– Part 1: Specifications for lubricants for enclosed gear systems*
- 120 ISO/TR 13593, *Enclosed gear drives for industrial applications*
- 121 ISO 14104, *Gears – Surface temper etch inspection after grinding*
- 122 ISO 14635-1, *Gears – FZG test procedures – Part 1: FZG test method A/8,3/90 for relative*
123 *scuffing load-carrying capacity of oils*
- 124 ISO 14635-1:2000, *Gears – FZG test procedures – Part 1: FZG test method A/8,3/90 for*
125 *relative scuffing load-carrying capacity of oils*
- 126 ISO 15243, *Rolling bearings – Damage and failures – Terms, characteristics and causes*

- 127 ISO 15243:2017, *Rolling bearings – Damage and failures – Terms, characteristics and*
128 *causes*
- 129 ISO/TS 16281, *Rolling bearings – Methods for calculating the modified reference rating*
130 *life for universally loaded bearings*
- 131 ISO/DIS 21920-1, *Geometrical product specifications (GPS) – Surface texture: Profile –*
132 *Part 1: Indication of surface texture*
- 133 ISO/DIS 21920-2, *Geometrical product specifications (GPS) – Surface texture: Profile –*
134 *Part 2: Terms, definitions and surface texture parameters*
- 135 ISO/DIS 21920-3, *Geometrical product specifications (GPS) – Surface texture: Profile –*
136 *Part 3: Specification operators*
- 137 ANSI/AGMA 6001, *Design and selection of components for enclosed gear drives*
- 138 ANSI/AGMA 6123, *Design manual for enclosed epicyclic gear drives*
- 139 ASTM D445, *Standard test method for kinematic viscosity of transparent and opaque*
140 *liquids (and calculation of dynamic viscosity)*
- 141 ASTM D664, *Standard test method for acid number of petroleum products by*
142 *potentiometric titration*
- 143 ASTM D974, *Standard test method for acid and base number by color-indicator titration*
- 144 ASTM D5185, *Standard test method for multielement determination of used and unused*
145 *lubricating oils and base oils by inductively coupled plasma atomic emission spectrometry*
146 *(ICP-AES)*
- 147 ASTM D6304, *Standard test method for determination of water in petroleum products,*
148 *lubricating oils, and additives by coulometric Karl Fischer titration*
- 149 DIN 471, *Circlips (retaining rings) for shafts: Normal type and heavy type*
- 150 DIN 472, *Circlips (retaining rings) for bores: Normal type and heavy type*
- 151 DIN 743, *Shafts and axles, calculations of load capacity, Parts 1, 2, 3*
- 152 DIN 3990-16, *Calculation of load capacity of cylindrical gears – Part 16: Determination of*
153 *the micro-pitting load-carrying capacity of lubricants using FZG-test-method GT-C/8,3/90*
- 154 DIN 6885-1, *Drive type fastenings without taper action; Parallel keys, keyways, deep*
155 *pattern*
- 156 DIN 6892, *Mitnehmerverbindungen ohne Anzug – Passfedern – Berechnung und*
157 *Gestaltung (available in German only)*
- 158 DIN 7190, *Interference fits – Calculation and design rules*

159 DIN 51399-1, *Testing of lubricants – Determination of elements content in additives, wear*
160 *and other contaminations – Part 1: Direct determination by optical emission spectral*
161 *analysis with inductively coupled plasma (ICP OES)*

162 DIN 51777, *Petroleum products – Determination of water content using titration according*
163 *to Karl Fischer*

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

167 FKM Guideline, *Analytical strength assessment of components*, VDMA Verlag

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

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

172 **3 Terms, definitions, and conventions**

173 **3.1 Terms and definitions**

174 For the purposes of this document, the terms and definitions given in IEC 61400-1:2019
175 and IEC 60050-415 as well as the following apply.

176 Note 1 to entry: The definitions in this standard take precedence.

177 **3.1.1**

178 **bearing manufacturer**

179 legal entity supplying bearings for the wind turbine gearbox, and who is responsible for
180 the design and the application engineering of the bearing

181 Note 1 to entry: Typically, the bearing supplier will also manufacture the bearing.

182 **3.1.2**

183 **characteristic load**

184 load value having a prescribed probability of not being attained

185 Note 1 to entry: See also IEC 61400-1 and 3.1.4, design load.

186 Note 2 to entry: Commonly, the characteristic load is the value derived from measurement or simulation
187 without adjustment for uncertainty or partial safety factors.

188 **3.1.3**

189 **design life**

190 specified duration for which strength verification shall be performed

191 Note 1 to entry: There is no failure probability and confidence associated with the term design life, and it
192 shall not be confused with the attainable service life (see 3.1.22).

193 Note 2 to entry: Some serviceable components and wear parts may have a lower design life than the one
194 specified for the entire gearbox.

195 **3.1.4**

196 **design load**

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

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

200 **3.1.5**

201 **design validation**

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

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

205 **3.1.6**

206 **design verification**

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

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

210 **3.1.7**

211 **equivalent load**

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

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

216 **3.1.8**

217 **excitability**

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

220 **3.1.9**

221 **extreme load**

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

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

225 **3.1.10**

226 **gearbox manufacturer**

227 entity responsible for designing the gearbox, and specifying manufacturing requirements
228 for the gearbox and its components

229 Note 1 to entry: In reality, several legal entities can be involved in this process, which is not further reflected
230 in this standard.

231 **3.1.11**

232 **interface**

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

235 **3.1.12**

236 **load reserve factor *LRF***

237 ratio of the design load to the maximum allowable load on a specific component

238 Note 1 to entry: *LRF* can be determined separately for both the ultimate and fatigue strength calculation.

239 **3.1.13**

240 **local failure**

241 failure which occurs when at a critical location, the maximum allowable strain is exceeded

242 **3.1.14**
243 **maximum operating load**
244 highest load determined by the design load cases used in fatigue analysis as defined in
245 IEC 61400-1, including partial load safety factor as applicable in accordance with
246 IEC 61400-1

247 **3.1.15**
248 **model validation**
249 process of determining the degree to which the model is an accurate representation of
250 corresponding physical experiments from the perspective of the intended uses of the
251 model

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

253 **3.1.16**
254 **model verification**
255 process of determining that a computational model accurately represents the underlying
256 mathematical model and its solution

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

258 **3.1.17**
259 **nacelle**
260 turbine structure above the tower that holds the drivetrain, generator, other
261 subcomponents, and parts of the controls and actuation systems

262 **3.1.18**
263 **non-locating bearing**
264 bearing supporting only radial load

265 **3.1.19**
266 **rainflow matrices**
267 representation of fatigue loads using a two-dimensional matrix containing counts of cycle
268 occurrence within sub-ranges of cyclic means and amplitudes

269 Note 1 to entry: See Annex A.

270 **3.1.20**
271 **reference power**
272 arbitrarily chosen datum within the range of power set points of the wind turbine variants
273 for which a gearbox type is designed

274 Note 1 to entry: In accordance with IECRE OD-501, the actual rated power set point of any wind turbine
275 variant using this gearbox type may deviate by 5 % from this reference value. See Annex A for explanations.

276 **3.1.21**
277 **reference speed**
278 arbitrarily chosen datum within the range of speed set points of the wind turbine variants
279 for which a gearbox type is designed

280 Note 1 to entry: In accordance with IECRE OD 501, the actual rated speed set point of any wind turbine
281 variant using this gearbox type may deviate by ± 2 % from this reference value. See A.5 for explanations.

282 **3.1.22**
283 **reference torque**
284 torque value calculated from reference power and reference speed divided by the
285 efficiency of the wind turbine, within the range of torque set points of the wind turbine
286 variants for which a gearbox type is designed

Note 1 to entry: The efficiency number used to calculate reference torque shall include all mechanical and electrical losses between rotor and the power curve measurement point, at least including gearbox, generator, and power converter. See A.5 for explanations.

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.

3.1.25
wind turbine manufacturer

entity responsible for specifying the requirements for the gearbox designed in accordance with this standard

Note 1 to entry: Typically, the wind turbine manufacturer will design, manufacture and market the wind turbine.

3.2 Conventions

3.2.1
shaft designations – examples for typical wind turbine gearbox architecture

Figure 1 shows the designations of shafts in 3-stage parallel shaft gearboxes. In 4-stage gearboxes, the intermediate shafts are called “low-speed intermediate shaft”, “medium-speed intermediate shaft”, and “high-speed intermediate shaft”.

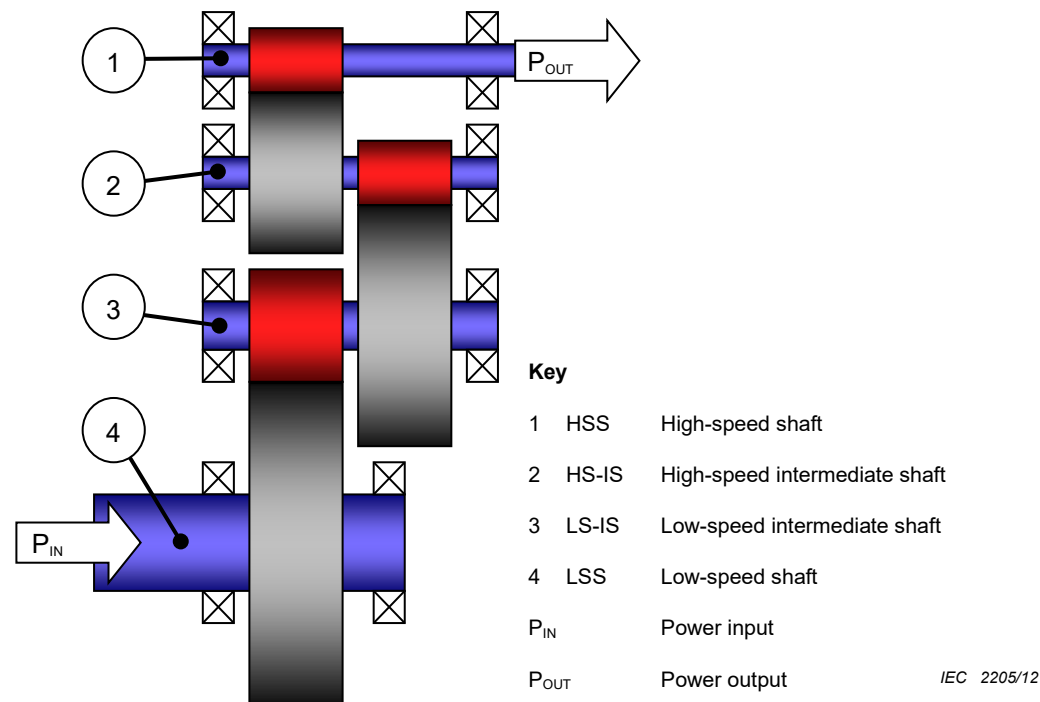


Figure 1 – Shaft designation in 3-stage parallel shaft gearboxes

Figure 2 shows the designations of shafts in 3-stage gearboxes with one planet stage.

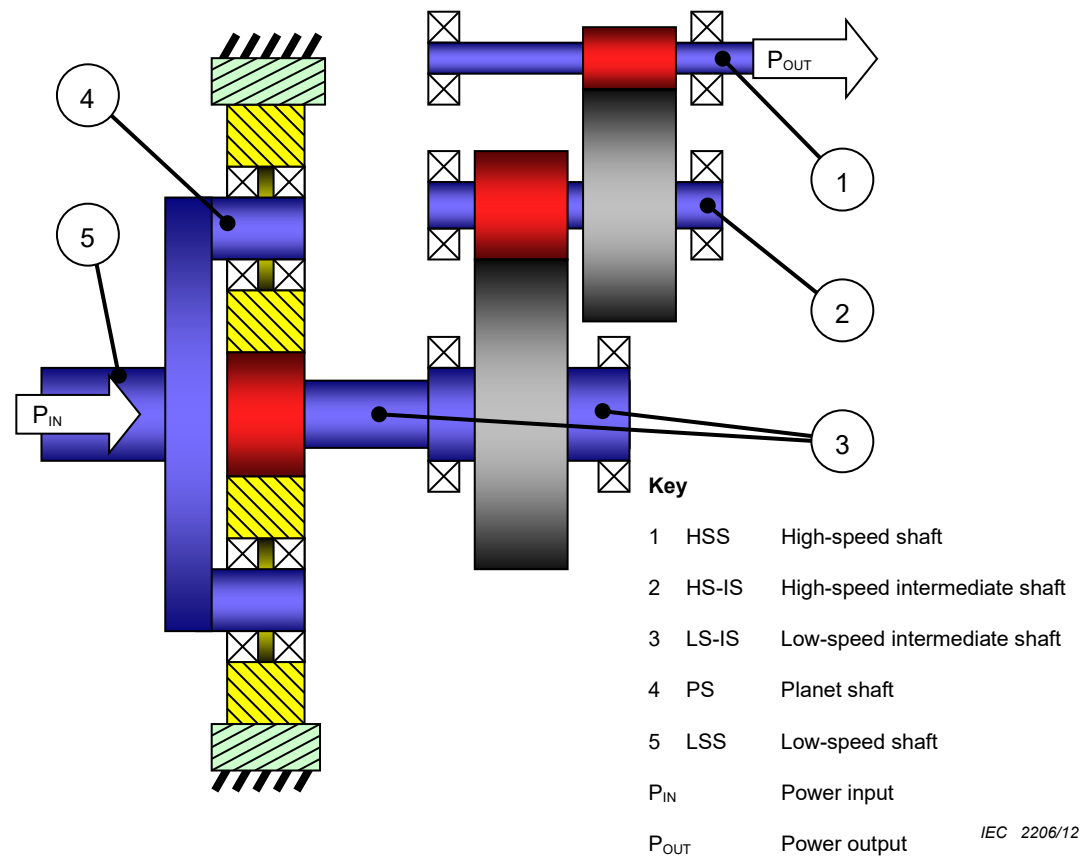


Figure 2 – Shaft designation in 3-stage gearboxes with one planet stage

Figure 3 shows the designations of shafts in 3-stage gearboxes with two planet stages.

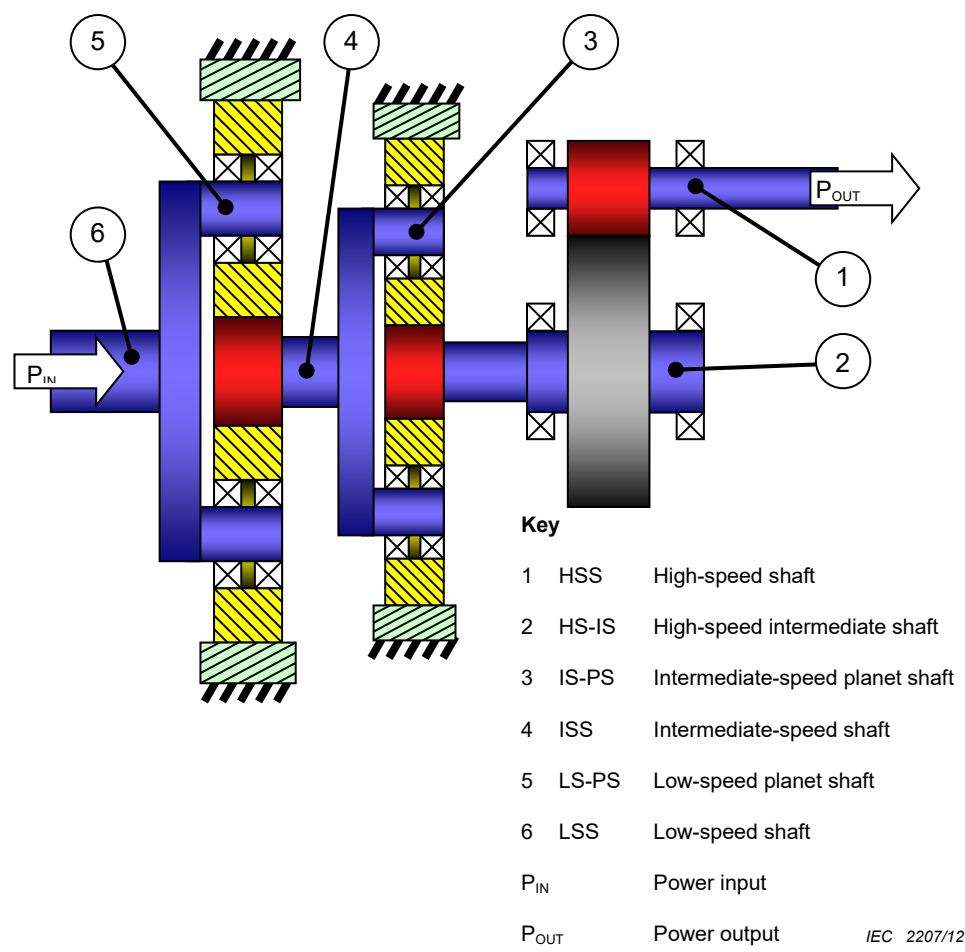


Figure 3 – Shaft designation in 3-stage gearboxes with two planet stages

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_{PL}	planet wheel facewidth	mm
D_{pw}	working pitch diameter	mm
E	modulus of elasticity (Young's modulus)	MPa
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_e	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_{cr}	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_e	elastic load limit, the load at which the local stress in the notch exceeds the yield point R_p	N or N·m
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_p	total plastic load limit, load at which the entire section starts yielding	N or N·m
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_{ij}	number of cycles in the i^{th} load level and j^{th} range level	–
$n_{pl,\sigma,GF}$	section factor for global failure local stress in relation to R_p	–
$n_{pl,\sigma,LF}$	section factor for local failure local stress in relation to R_p	–
q_i	time, if at constant speed, or revolutions at the i^{th} load level	–
R_a	arithmetic mean roughness	μm

Symbol	Description	Unit
R_j	j^{th} range level	–
R_{mr}	material ratio	%
R_p	yield strength (yield point or offset yield point at 0,2 % plastic strain)	MPa
R_q	root mean square deviation of the assessed shaft and plain bearing profiles	μm
R_z	mean peak-to-valley roughness	μm
S_B	safety factor for scuffing	–
S_F	safety factor for tooth breakage	–
S_H	safety factor for pitting	–
S_0	(bearing) static safety factor	–
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
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	–
α	angle of rotation	°
ε_{lim}	elastic plastic limit of notch strain	%
γ_f	partial safety factor for loads	–
γ_m	partial safety factor for material	–
γ_n	partial safety factor for consequence of failure	–
κ	viscosity ratio	–
$\lambda_{GF,min}$	minimum specific lubricant film thickness	–
λ_{GFP}	permissible specific lubricant film thickness	–
σ	stress (true stress)	MPa
σ_H	contact stress	MPa

328

329 **4.2 Abbreviations**

330 Abbreviations are given in Table 2.

331

Table 2 – Abbreviations

Abbreviation	Description
AGMA	American Gear Manufacturers Association
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CEC	Commission of the European Communities

Abbreviation	Description
DIN	Deutsches Institut für Normung
DLC	design load case as used in IEC 61400-1
EHL	elasto-hydrodynamic lubrication
EP	extreme pressure
EXT	extreme load (matrices)
FAT	factory acceptance testing
FEA	finite element analysis
FKM	Forschungskuratorium Maschinenbau
FMEA	failure mode and effects analysis
FVA	Forschungsvereinigung Antriebstechnik
FZG	“Forschungsstelle für Zahnräder und Getriebebau” TU Munich
GfT	Gesellschaft für Tribologie
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
LDD	load duration distribution (histogram)
LRD	load revolution distribution (histogram)
LS-IS	low-speed intermediate shaft
LS-PS	low-speed planet shaft (or axle)
LSS	low-speed shaft
NVH	noise, vibration, and harshness
PS	planet shaft (or axle)
PTO	power take-off, additional output shafts driving auxiliary equipment such as lubricant pumps
RFC	rainflow cycle count
SPC	statistical process control
TFF	tooth flank fracture
VDI	Verein Deutscher Ingenieure
WEC	white etching crack

332

333 **5 Design process**334 **5.1 General**

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

5.2 Gearbox type

Gearbox designs are commonly organized in families (or platforms) to cater for the operating conditions in different variants of a wind turbine family, such as different grid frequency, different rotor diameters, or different power ratings. Gearbox variants within such a family use the same design basis and share components, modules (e.g. a complete planetary stage), concepts, technologies, components and manufacturing processes.

Variants within one gearbox families can commonly be considered of the same type if their design and operating parameters are within the ranges specified in Table 3. Derived variants within the family may be verified by similarity as described in 8.4.3 as long as the following criteria are met:

- the variant meets the minimum calculated safety factors and lifetime at the specified minimum design lifetime in accordance with Clause 7;
- the risk assessment (see 5.5) does not indicate new failure modes;
- at least one variant of the family is verified and validated in accordance with Clause 8;

Table 3 – Definition of a gearbox family

Commonality criteria	Difference with verified gearbox type
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 materials	same base material and heat treatment process (unless relevant experience can be proven from other applications)
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 %

5.3 Design life, operational lifetime, and reliability

The design life of the gearbox should at least be the same as for the wind turbine. IEC 61400-1 requires that the design life of a wind turbine for wind classes I to III shall be at least 20 years.

The loads compiled for this design life are used to design and rate the gearbox components according to specific design standards. These design standards (e.g. ISO 6336 or ISO 281) are written for general applications and do not stipulate safety factors or design life to meet the requirements for specific applications. The results of these component standards are expressed in different metrics, such as safety factors, lifetime, and/or probabilities of failure which makes it difficult to derive a common theoretical design reliability for a wind turbine gearbox.

IEC/TS 61400-4-1 suggests a method for comparing theoretical design reliability of a gearbox as function of the operational lifetime. The assessment is limited to failure modes where generally recognized calculation methods exist, so not all relevant failure modes in wind turbine gearboxes may be covered. Within these limitations, the method allows the comparison of calculated design reliability between different gearbox designs, or comparison of different operating conditions on a gearbox design.

Scheduled maintenance and even scheduled (or preventive) replacement of components can be applied to increase the availability and reliability of the gearbox. Components with a design life less than that specified for the entire gearbox shall be serviceable or replaceable. The expected design life of these components shall be specified as part of the operations and maintenance documentation. 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 defines component classes as a function of the consequences of failure.

- The gearbox will typically fall into class 2 which applies to a "safe life" structural component whose failure can lead to the failure of a major part of a wind turbine.
- Depending on the actual system design, some parts of the gearbox can fall into class 3 for "safe life" mechanical components, if the gearbox supports actuators, brakes or blocking devices that are part of non-redundant wind turbine protection functions.

The partial safety factor for consequence of failure, γ_n , shall be chosen from IEC 61400-1 accordingly. Any class 3 components according to IEC 61400-1 within the gearbox 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 4 can be used as a starting point.

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. For design changes, only the changed components and their impact on the system should be addressed. The system analysis should include:

- 399 • relevant design load cases;
- 400 • system architecture;
- 401 • interfaces;
- 402 • interface requirements;
- 403 • functional requirements for each element;
- 404 • potential failure modes;
- 405 • potential consequences of failure;
- 406 • limited life components;
- 407 • lubrication and cooling;
- 408 • manufacturing quality demands;
- 409 • service and maintenance;
- 410 • monitoring;
- 411 • transportation;
- 412 • installation;
- 413 • commissioning.

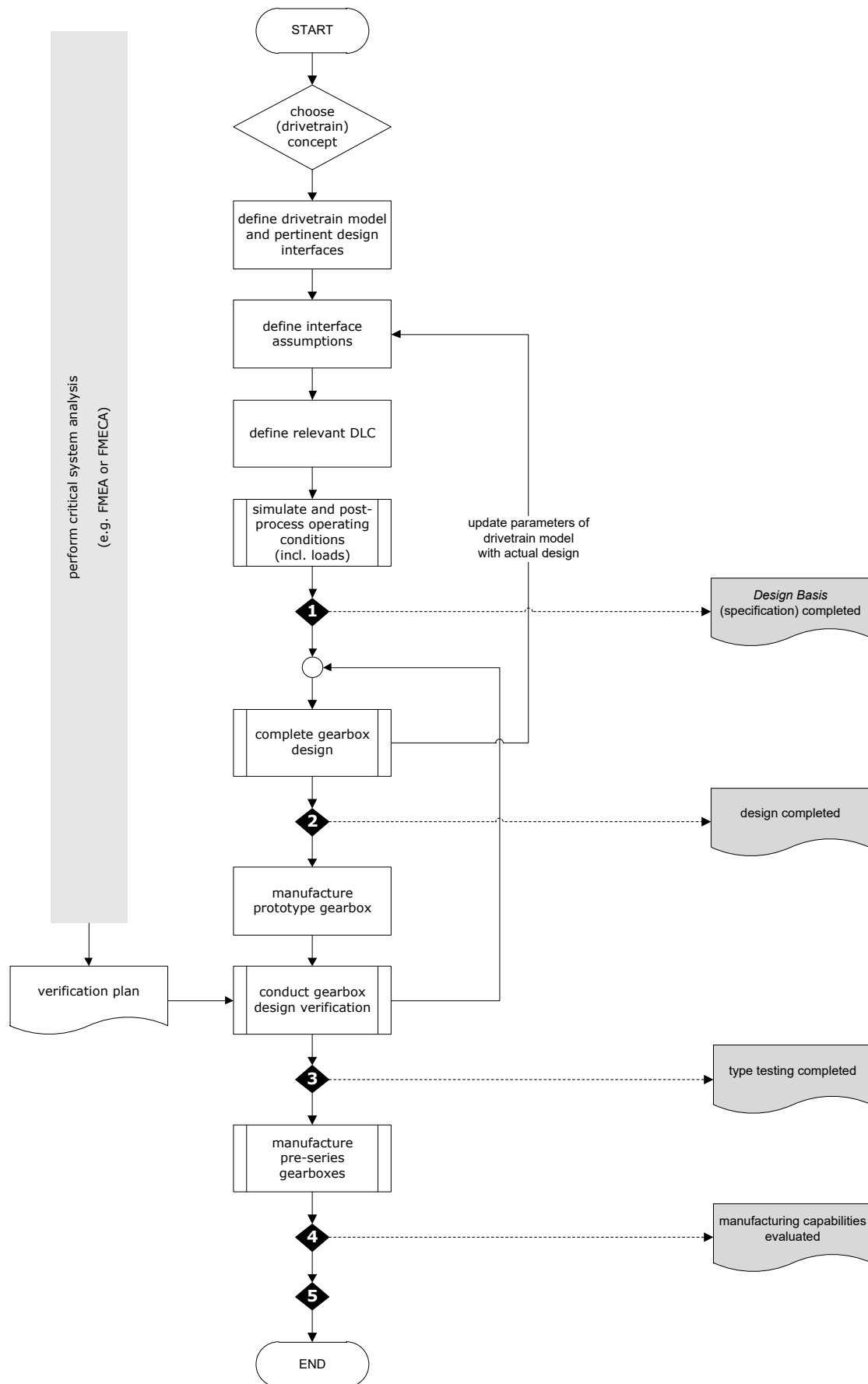


Figure 4 – Design process flow chart

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. Design choices which can significantly define the drivetrain initial conceptual design. 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) can be defined per IEC 61400-1, 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 taken into account 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 4.

With the loads and operational characteristics defined and specified, the initial gearbox design can take place. Because the actual design details of the gearbox affects 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. These estimates should be verified in subsequent testing, and the results be included in further simulations and design analysis. Analytical strength assessment as described in this standard concludes the design phase, as shown as milestone <2> in Figure 4.

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 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 4. 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 4 includes the completion of preparations for serial production.

Milestone <5> in Figure 4 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 (design requirements for fixed offshore wind turbines) or IEC/TS 61400-3-2 (design requirements for floating offshore wind turbines).

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 may 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:

- 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 loads, fatigue loads and duration loads;
- duration and frequency of occurrence;
- contemporaneous loads associated with design driving extreme loads. Guidance for presentation format is provided 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. Purpose of the analysis is the identification of load levels which exceed those predicted by the global aeroelastic model of the wind turbine.

The analysis of noise transmission and -emission (e.g. tonal emission at gear mesh frequencies) is not covered within the scope of this edition of the standard.

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 frequencies at which excitability occurs can be significantly higher than the common resolution of global aeroelastic models, so a drivetrain analysis with sufficient fidelity to capture higher frequency response is necessary. From experience, excitations up to 350 Hz are relevant for the wind turbine system. 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 all relevant gearbox components, at least including gears, shafts, planet carriers, bearings, and relevant parts of the gearbox 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 can be represented as one mass.

The analysis model shall have at least a torsional degree of freedom for all gearbox elements and allow solid body rotation of the gearbox against the torque supports. Additional degrees of freedom shall be added to the model in case non-torsional eigenmodes occur, for example:

- the gearbox design is susceptible to rocking of shafts in axial direction, requiring a model with an additional degree of freedom in axial direction and representation of bearing axial stiffness;
- wobbling or teeter modes of gearbox components are suspected relevant, requiring a model with angular degrees of freedom for these components;

- torsional modes couple with bending modes, requiring a model with flexible bodies.

Significant differences between simulated and measured eigenfrequencies as described in 6.4.5 may indicate the onset of such effects.

Relevant input parameters, such as stiffness, should be calculated according to relevant component standards or by analytical or numerical calculation models. Alternatively, representative test data (e.g. from similar designs) may be used.

Gear mesh stiffness shall be represented in the model as a constant mean value over one mesh period. Analyses in the time domain shall include the mesh excitation behaviour based on transmission error or dynamic mesh stiffness calculations. Alternatively, a higher order excitation function (e.g. Fourier series) may be used.

6.4.3 Required analyses

6.4.3.1 Scope

The analysis shall cover the complete operating speed range of all wind turbine versions that the gearbox family is targeting, including their different operating modes (e.g. noise reduced operation).

6.4.3.2 Modal analysis and energy distribution

The modal analysis and corresponding eigenvalues, eigenfrequencies and mode shapes shall be calculated from a linearized operating state. If non-linear effects such as centrifugal stiffening of the blade are considered, the model shall be linearized at representative torque and speed points through normal operation.

6.4.3.3 Campbell diagram

A Campbell diagram shall be used to display the analysis results, including:

- the fundamental forcing frequencies and their relevant harmonics, such as gear mesh, shaft rotation, rotor rotation, blade pass, generator pole pass or generator slot pass;
- torsional eigenfrequencies of the drivetrain that are influenced by gearbox components.

If the assessment of excitability suggests that non-torsional eigenfrequencies play a significant role in the dynamic response of the system, the Campbell diagram should include these eigenfrequencies.

Potential resonances identified at the intersection of a forcing frequency including its harmonics with an eigenfrequency should be analysed.

6.4.3.4 Transient analysis

The following transient events shall be analysed:

- fault ride through;
- short circuit events (Note: For these special operating conditions time series with higher sampling frequency are necessary).

All operating conditions where dynamic responses can occur at higher frequencies than commonly covered by aeroelastic codes (typically ≈ 25 Hz) should be evaluated.

Depending on the turbine control strategy, the following operating conditions should be evaluated: