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Gear Manufacturers
Association

ANSI/AGMA 6006-B20
(Revision of ANSI/AGMA/AWEA 6006-A03)

American National Standard

Standard for Design and Specifications of Gearboxes for Wind Turbines

ANSI/AGMA 6006-B20

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**American
National
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ANSI/AGMA 6006-B20

[Revision of ANSI/AGMA/AWEA 6006-A03]

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ABSTRACT

This standard is intended to apply to wind turbine gearboxes. It provides information for specifying, selecting, designing, manufacturing, testing, procuring, operating and maintaining reliable speed increasing gearboxes for wind turbine generator system service.

Annex information is supplied on wind turbine architecture, wind turbine load description, quality assurance, operation and maintenance, minimum purchaser gearbox manufacturer ordering data, lubrication selection and monitoring, determination of an application factor from a load spectrum using the equivalent torque, and bearing stress calculations.

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Foreword

[The foreword, footnotes and annexes, if any, in this document are provided for informational purposes only and are not to be construed as a part of ANSI/AGMA 6006-B20, *Standard for Design and Specification of Gearboxes for Wind Turbines*.]

The operation and loading of a wind turbine speed increasing gearbox is unlike most other gear applications. The intent of this standard is to describe the differences. Much of the information is based on field experience. This standard is a tool whereby wind turbine and gearbox manufacturers can communicate and understand each other's needs in developing a gearbox specification for wind turbine applications. The annexes present informative discussion of various issues specific to wind turbine applications and gear design.

A combined committee of AWEA and AGMA members representing wind turbine manufacturers, operators, researchers, consultants, and gear, bearing and lubricant manufacturers were responsible for the drafting and development of this standard.

The committee first met in 1993 to develop AGMA/AWEA 921-A97, *Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems*. The AGMA Information Sheet was approved by the AGMA/AWEA Wind Turbine Gear Committee on October 25, 1996 and by the AGMA Technical Division Executive Committee on October 28, 1996. This standard supersedes AGMA/AWEA 921-A97.

The first draft of ANSI/AGMA/AWEA 6006-A03 was made in March 2000. It was approved by the AGMA membership in October 2003. It was approved as an American National Standard on January 9, 2004.

In 2005, ANSI/AGMA/AWEA 6006-A03 was adopted internationally as International Standards Organization (ISO) 81400-4, *Wind Turbines – Part 4: Design and Specification of Gearboxes*.

The International Electrotechnical Commission (IEC) published IEC 61400-4 in 2012, updating the initial work established in ANSI/AGMA/AWEA 6006-A03.

ANSI/AGMA 6006-B20 is a revision of ANSI/AGMA/AWEA 6006-A03. This edition continues the development from the previous standards to provide concise requirements for gearbox design and specifications as well as introducing a reliability calculation method.

The first draft of ANSI/AGMA 6006-B20 was created in July 2016. It was approved by the AGMA membership in August 2, 2019. It was approved as an American National Standard on February 11, 2020.

Suggestions for improvement of this standard will be welcome. They may be submitted to tech@agma.org.

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American National Standard –

Standard for Design and Specifications of Gearboxes for Wind Turbines

1 Scope

This standard is applicable to enclosed speed increasing gearboxes for horizontal axis wind turbine drivetrains with a power rating in excess of 500 kW. This applies to wind turbines installed both onshore and offshore. This standard applies to modular and integrated designs.

The standard provides guidance on the application of the wind turbine loads in relationship to the design of gears and gearbox elements. A standardized method for calculating gearbox reliability is included which allows for an objective comparison of different gearbox designs. Furthermore, this method provides a means to evaluate designs based upon gearbox lifetime economics.

The gearing elements referenced include spur, helical or double helical and their combinations in parallel and epicyclic arrangements in the main power path.

The standard applies to designs using rolling element bearings. Plain bearings are permissible, although their use and rating is not covered.

Guidance is included on the specification of shafts, shaft interfaces and fits, bearings and gear housing structure.

Lubrication of the gearbox is covered along with prototype and production testing.

2 Normative references

The following documents contain provisions which, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions were valid. All standards are subject to revision and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below.

ANSI/AGMA ISO 6336-6-A08, *Calculation of Load Capacity of Spur and Helical Gears – Part 6: Calculation of Service Life Under Variable Load*

AGMA 925-, *Effect of Lubrication on Gear Surface Distress*

AMS 2301, *Steel Cleanliness, Aircraft Quality Magnetic Particle Inspection Procedure*

ANSI/AGMA ISO 1328-1, *Cylindrical Gears – ISO System of Accuracy – Part 1: Definitions and Allowable Values of Deviations Relevant to Corresponding Flanks of Gear Teeth*

ANSI/AGMA 6001, *Design and Selection of Components for Enclosed Gear Drives*

ANSI/AGMA 9005-F16, *Industrial Gear Lubrication*

ASTM-A388-16, *Standard Practice for Ultrasonic Examination of Steel Forgings*

ASTM-E127, *Standard Practice for Fabrication and Control of Flat Bottomed Hole Ultrasonic Standard Reference Blocks*

ASTM-A485, *Standard Specification for High Hardenability Antifriction Bearing Steel*

ASTM-A534, *Standard Specification for Carburizing Steels for Anti-Friction Bearings*

DIN 471, *Retaining Rings for Shafts – Normal Type and Heavy Type*

ANSI/AGMA 6123-, *Design Manual for Enclosed Epicyclic Gear Drives- Chair to approve*

ISO 7089, *Plain washers – Normal Series – Product Grade A*

DIN 743, *Parts 1–4, Calculation of Load Capacity of Shafts and Axles*

DIN 6885-2, *Drive Type Fastenings without Taper Action; Parallel Keys, Deep Pattern of Machine Tools, Dimensions and Applications*

DIN 6892, *Drive Type Fastenings without Action – Parallel Keys – Calculation and Design*

DIN 7190-1, *Interference fits - Part 1: Calculation and design rules for cylindrical self-locking pressfits*

DIN 7190-2, *Interference fits - Part 2: Calculation and design rules for conical self-locking pressfits*

DIN 51517-3, *Lubricants – Lubricating Oils – Part 3: Lubricating Oils CLP, Minimum Requirements*

IEC 61400-1, *Wind Turbines – Part 1: Design Requirements*

IEC 61400-3, *Wind Turbines – Part 3: Design Requirements for Offshore Wind Turbines*

IEC 61400-4, *Wind Turbines – Part 4: Design Requirements for Wind Turbine Gearboxes*

IECRE OD 501-2: *Conformity Assessment and Certification of wind turbine gearboxes by RECB*

ISO 76, *Rolling Bearings – Static Load Ratings*

ISO 281, *Rolling Bearings – Dynamic Load Rating and Rating Life*

ISO 683, *Parts 1–18, Heat Treatable Steels*

ISO 1302:2002, *Geometrical Products Specifications (GPS) – Indication of Surface Texture in Technical Product Documentation*

ISO 3274:1996, *Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Nominal Characteristics of Contact (Stylus) Instruments*

ISO 4287:1997, *Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Terms*

ISO 4288:1996, *Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Rules and Procedures for the Assessment of Surface Texture*

ISO 4406, *Hydraulic Fluid Power – Fluids – Method for Coding the Level of Contamination by Solid Particles*

ISO 6336-1, *Calculation of Load Capacity of Spur and Helical Gears – Part 1: Basic Principles, Introduction and General Influence Factors*

ISO 6336-2, *Calculation of Load Capacity of Spur and Helical Gears – Part 2: Calculation of Surface Durability (Pitting)*

ISO 6336-3, *Calculation of Load Capacity of Spur and Helical Gears – Part 3: Calculation of Tooth Bending Strength*

ISO 6336-5, *Calculation of Load Capacity of Spur and Helical Gears – Part 5: Strength and Quality of Materials*

ISO/TR 10064-3, *Cylindrical Gears – Code of Inspection Practice – Part 3: Recommendations Relative to Gear Blanks, Shaft Centre Distance and Parallelism of Axes*

ISO 12925-1, *Lubricant, Industrial Oils and Related Products (Class L) – Family C (Gears) – Part 1: Specifications for Lubricants for Enclosed Gear Systems*

ISO/TR 13593, *Enclosed Gear Drives for Industrial Applications*

ISO/TS 6336, *Calculation of Load Capacity of Spur and Helical Gears – Part 20: Calculation of Scuffing Load Capacity (also applicable to bevel and hypoid gears) – Flash Temperature Method*

ANSI/AGMA ISO 14104-A17, *Gears – Surface Temper Etch Inspection After Grinding, Chemical Method*

ISO 14635-1, *Gears – FZG Test Procedures – Part 1: FZG Test Method A/8, 3/90 for Relative Scuffing Load-Carrying Capacity of Oils*

ISO/TS 16281, *Rolling Bearings – Methods for Calculating the Modified Reference Rating Life for Universally Loaded Bearings*

3 Terms, definitions and conventions

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61400-1:2005 and IEC 60050-415 [1] as well as the following apply.

3.1.1 Bearing manufacturer

Legal entity supplying bearings for the wind turbine gearbox, and who is responsible for the design and the application engineering of the bearing.

NOTE: Typically, the bearing supplier will also manufacture the bearing.

3.1.2 Certification body

Entity that conducts certification of conformity of the wind turbine gearbox in accordance with IECRE OD501-2.

3.1.3 Characteristic load

Load value having a prescribed probability of not being exceeded.

3.1.4 Design lifetime

Specified duration for which strength verification shall be performed.

NOTE: Some serviceable components and wear parts may have a lower design lifetime than the one specified for the entire gearbox.

3.1.5 Design load

Load for which the strength of any component has to be documented.

NOTE: It consists of the characteristic load multiplied by the appropriate partial safety factor for load. See also IEC 61400-1 and Clause 6.

3.1.6 Equivalent load

Load which when repeated for a specified number of cycles causes the same damage as the actual load variation based on a specified life exponent.

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

3.1.7 Extreme load

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

NOTE: This component can be a force, a moment, a torque or a combination of these.

3.1.8 Gearbox manufacturer

The entity responsible for designing the gearbox and specifying manufacturing requirements for the gearbox and its components.

NOTE: In reality, several legal entities may be involved in this process, which is not further reflected in this standard.

3.1.9 Interface

Defined 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 supplier

Legal entity supplying lubricants for the wind turbine gearbox through either the wind turbine manufacturer, the gearbox manufacturer, or the wind turbine owner.

NOTE: The lubricant supplier is responsible for the specification of the lubricant and the additive package, but will not necessarily produce any of the components or blend the final product.

3.1.11 Maximum operating load

Highest load determined by the design load cases used in fatigue analysis as defined in IEC 61400-1, including partial load safety factor as applicable in accordance with IEC 61400-1.

3.1.12 Nacelle

Turbine structure above the tower that holds the drivetrain, generator, other subcomponents, and parts of the controls and actuation systems.

3.1.13 Time series

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

NOTE: These time series together with their corresponding occurrences specify the load history during the entire design lifetime.

3.1.14 Wind turbine manufacturer

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

NOTE: Typically, the wind turbine manufacturer will design, manufacture and market the wind turbine.

3.1.15 Wind turbine owner

Entity who purchases and is responsible for operating the wind turbine.

NOTE: In practice, the owner may contract different legal entities to operate, service and maintain the wind turbine. This distinction is not further reflected in this standard.

3.2 Symbols, abbreviations, and units

Symbols, abbreviations, and units used within this document are listed in Table 1 and Table 2.

NOTE: The symbols used in this standard may differ from other AGMA Standards. The users should assure themselves that they fully understand the terms, definitions, and symbols as contained in this standard.

Table 1 – Symbols

Symbol	Description	Units
a_1	Life adjustment factor for reliability	–
(c)	Depth at which R_{mr} is calculated	μm
D_{pw}	Pitch diameter of the rolling element set in a bearing	mm
$f_{\Sigma\delta}$	Shaft parallelism in-plane deviation	mm
$f_{\Sigma\gamma}$	Resulting mesh misalignment caused by deviations of the shaft alignment to the ideal axis projected into the plane of action	mm
$f_{H\beta 1}$	Helix slope deviation; pinion	mm
$f_{H\beta 2}$	Helix slope deviation; gear	mm
$f_{\Sigma\beta}$	Shaft parallelism out-of-plane deviation	mm
f_{ma}	Gear mesh alignment	mm
i	Element being evaluated	–
K_γ	Mesh load factor	–

Symbol	Description	Units
$K_{F\alpha}$	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	–
$L_{10mr,i}$	Modified reference rating life at load level i and 10% failure probability	hrs
L_{nmr}	Modified reference rating life at failure probability n	hrs
L_{nr}	Combined basic reference life	hrs
m_n	Normal tooth module	mm
num	Number of elements comprising the system	–
n	Failure probability	%
N_L	Number of load cycles	–
P_{el}	Generator electrical power	kW
P_{max}	Approximated maximum contact pressure for line contact	MPa
q_i	Time- or cycle- or revolution share on the i^{th} load level	–
Q_{oil}	Oil volume	l
Ra	Arithmetic mean roughness (as specified in ISO 4287/ ISO 4288)	μm
Rmr	Material ratio (as specified in ISO 4287/ ISO 4288)	%
Rz	Mean peak-to-valley roughness (as specified in ISO 4287/ ISO 4288)	μm
S_0	(Bearing) static safety factor	–
S_F	Safety factor for gear tooth bending strength	–
S_H	Safety factor for surface durability	–
S_{Hmin}	Minimum safety factor for surface durability	–
S_{Fmin}	Minimum safety factor for gear tooth bending strength	–
t	Time	hours
Y_{NT}	Life factor for tooth-root stress for reference test conditions	–
Y_{Sg}	Stress correction factor for gears with notches in fillets	–
Z_{NT}	Life factor for contact stress for reference test conditions	–
κ	Viscosity ratio	–
σ_{FE}	Allowable stress number (bending)	MPa
σ_{Hlim}	Allowable stress number (contact)	MPa
β	Weibull shape parameter (or slope) for a single part	–
γ	Weibull shift parameter. No failure can occur before γ hours, so the time scale is shifted to start at γ and not at 0.	hours
η	Scale parameter of the Weibull distribution.	hours
σ	Normal distribution standard deviation	hours

Symbol	Description	Units
μ	Normal distribution mean	hours
λ	Scale parameter of the exponential distribution	1/hours
t_d	Design life, typically 175 200 hours for a 20-year design life	hours
p	Material S/N curve slope exponent	–
R_o	Rated reliability of component	–
R_{sys}	System reliability	–
R_e	Element reliability	–

Table 2 – Abbreviations

Abbreviation	Description
4PCBB	4-point contact ball bearing
AGMA	American Gear Manufacturers Association
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CEC	Commission of the European Communities
CRB	Cylindrical roller bearing
BB	Deep-groove ball bearing
DFMEA	Design failure mode and effect analysis
DIN	Deutsches Institut für Normung
DLC	Design load cases as used in IEC 61400-1
EHL	Elasto-hydrodynamic lubrication
FEA	Finite element analysis
fc CRB	Full-complement cylindrical roller bearing
HS-IS	High-speed intermediate shaft
HSS	High-speed shaft
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LS-IS	Low-speed intermediate shaft
LSS	Low-speed shaft
MQ	Material Quality grade as defined in ISO 6336
NPT	National pipe thread
PTO	Power Takeoff Unit
O&M	Operations and maintenance
RMS	Root mean square
TRB	Tapered roller bearing

4 Design for reliability

4.1 Design process

A comprehensive gearbox reliability design procedure shall be performed. The procedure will treat the gearbox as a single system consisting of all its component parts. All failure modes of all component parts will be addressed. This gearbox reliability design procedure is composed of two parallel paths of action that deal with two different types of components.

The first path addresses the reliability of all the gearbox components and failure modes that, for the specified duty cycle, cannot be assigned a life. Industry standard analysis methods that would result in a calculated life do not exist for these components. Reliability of this first group of components, and their failure modes, is addressed by special analysis, DFMEA, and testing.

A few examples of these component failure modes are gear scuffing, static structural strength of housings, and static structural strength of bolted joints.

The second path addresses the reliability of all the gearbox components for which a life can be calculated for a specified duty cycle. These component lifetimes will be used to calculate the gearbox reliability according the method described in Clause 5.2.

Therefore, this comprehensive procedure addresses the reliability of all components.

4.2 Serviceable components

Components with a design lifetime less than that specified for the entire gearbox shall be serviceable or replaceable up-tower. The expected design life of these components shall be specified as part of the operations and maintenance documentation. The service interval shall be specified.

5 Calculated gearbox reliability

5.1 Introduction

Gearbox failure is a significant factor in the operating expenses of a wind turbine. As a result, there is increasing desire for accurate gearbox failure assessment from owners and operators. The deterministic approach in prevailing standards provides only design safety factors for a given load spectrum. Herein, a standardized method for calculating gearbox reliability over time is described.

A standard system reliability calculation method allows improved communication between interested parties. Designers and manufacturers will have a means to standardize reliability evaluation of various design solutions and load spectra. Owners and operators receive a tool for comparing different wind turbine designs on equal terms. Manufacturers and operators can use the information for defining field service and repair strategies.

5.2 Method description

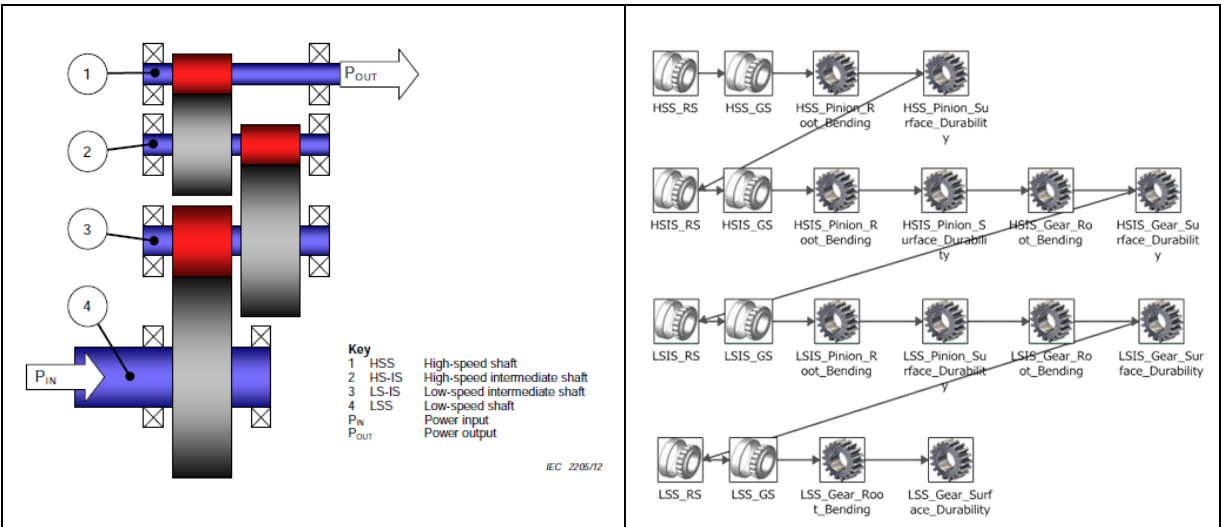
A reliability calculation shall be performed, and the calculated reliability shall be agreed upon between the turbine and gearbox manufacturer. This system reliability calculation will provide a reliability assessment based on the congregation of gearbox components and failure modes considered. The reliability calculation shall treat each unique failure mode of each gearbox component as an individual reliability element. The reliability elements are to be arranged in a single series so that, for calculation purposes, a failure of any one element results in the failure of the gearbox. Furthermore, the calculation shall be arranged such that the reliability of each gearbox stage can be individually assessed.

The assessment shall include all fatigue failure modes for which a life can be estimated by means of a proven and robust calculation method, currently including:

- gear tooth bending strength, S_F , per ISO 6336-3;
- gear tooth surface durability (pitting), S_H , per ISO 6336-2;
- modified reference bearing life (L_{nmr} , reference ISO/TS 16281).

For use in the reliability calculation, the bearing L_{nmr} shall be reported for each row of rolling elements.

The methodology described could be expanded to include additional unique failure modes that demonstrate a similarly proven and robust life calculation or are supported by empirical data. Figure 1 represents a simple shaft configuration to demonstrate the system reliability block diagram arrangement. A typical wind turbine gearbox has a more complex configuration. See Annex A for a typical gearbox configuration and reliability diagram.



5.3 Reliability calculations

5.3.1 System reliability

The reliability of the gearbox system at the specified design life is the product of the individual reliability elements.

$$R_{sys}(t) = \prod_{i=1}^{num} R_{e,i}(t) = R_{e,1}(t) \times R_{e,2}(t) \times \dots \times R_{e,num}(t) \tag{1}$$

where:

- R_e is as described in Clause 5.3.2;
- i is the element being evaluated;
- num is the total number of elements comprising the system.

5.3.2 Element reliability

As defined in Clause 5.2, each unique failure mode of any gearbox component is a reliability element. The reliability calculation for each element depends upon the failure distribution of the specific failure mode. The reliability equations are listed in Table 3 for normal, exponential, and 2- and 3- parameter Weibull distributions.

Table 3 – Reliability formula for various distributions

Weibull distribution, 2-parameter:	$R_e(t) = e^{-\left(\frac{t}{\eta}\right)^\beta}$
Weibull distribution, 3-parameter:	$R_e(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^\beta}$
Normal distribution:	$R_e(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_t^\infty e^{-\left(\frac{(t-\mu)^2}{2\sigma^2}\right)} dt$
Exponential distribution:	$R_e(t) = e^{-\lambda t}$

5.3.3 Reliability element calculation parameters

Weibull parameters for the purpose of calculation shall be as described in Table 4. If a manufacturer has sufficient experience and data to justify alternate parameters, then the alternative calculations can be provided in addition to the required calculation. For details on reliability parameters used in the Table 4, see Annex A.

Table 4 – Reliability parameters

	Gear tooth bending strength, S_F	Gear tooth surface durability (pitting), S_H	Bearing fatigue
Required factors			
Rated reliability (R_o)	0.99	0.99	0.90 per IEC 61400-4
Material slope factor (p)¹	ANSI/AGMA ISO 6336-6-A08	ANSI/AGMA ISO 6336-6-A08	ISO 281
Recommended factors			
Aging factor, t_d (hrs)²	175 200	175 200	175 200
Reliability distribution	2-P Weibull	2-P Weibull	3-P Weibull
Beta (β) shape	1.8	1.5	1.5
Eta (η) scale (hrs)	$\eta = \frac{t_d \times (S_F / S_{Fmin})^p}{\sqrt[p]{-\ln(R_o)}}$ where: $S_{Fmin} = 1.56$ Per reference method Miner's Rule ANSI/AGMA ISO 6336-6-A08	$\eta = \frac{t_d \times (S_H / S_{Hmin})^p}{\sqrt[p]{-\ln(R_o)}}$ where: $S_{Hmin} = 1.25$ Per reference method Miner's Rule ANSI/AGMA ISO 6336-6-A08	$\eta = \frac{L_{10mr} - \gamma}{\sqrt[p]{-\ln(R_o)}}$ where: L_{10mr} per ISO/TS 16281
Gamma (γ) location (hrs)	-	-	$\gamma = 0.05 \times L_{10mr}$
NOTES: ¹ The material slope factors for pitting and bending are obtained from the Table A-1 in ANSI/AGMA ISO 6336-6-A08. ² Typical design life is 20 years (175 200 hrs). Other design life values shall be agreed upon and documented by gearbox and turbine manufacturers.			

5.4 Example calculation

For an example of the reliability calculation for a typical wind turbine gearbox (long hand and spreadsheet format) see Annex A.

5.5 Additional calculations considering serviceable components

Serviceability of the gearbox is an important factor to be considered during the design process. The calculated reliability shall be reported by serviceable and non-serviceable components. The serviceable components shall be agreed upon by the gearbox manufacturer and the turbine manufacturer. There may be multiple degrees of service intervention.

6 Design verification documentation

All steps in the specification, design and verification process shall be documented. A summary table for the recommended documentation is contained in IEC 61400-4:2012, Annex F.

7 Quality plan

The methods and processes used to control the manufacturing of the gearbox elements shall be documented as part of a quality plan.

8 Drivetrain operating conditions and loads

8.1.1 Wind turbine load calculations

The operating conditions at each of the agreed interfaces shall be determined in accordance with IEC 61400-1 or IEC 61400-3. IEC 61400-1 or IEC 61400-3 define a minimum set of DLC that shall be considered in the design of a wind turbine.

8.1.2 Reliability of load assumptions

The fatigue and ultimate load functions for a given component shall be compared with the related resistance functions as described in IEC 61400-1 or IEC 61400-3 taking into account the proper partial safety factors for loads, materials and consequence of failure. The loading shall be verified through load measurements on a wind turbine as described in IECRE OD501-2 and in Clause 13.5.

9 Gears

9.1 Gear ratings

Standardized calculation methods for rating the capacity of gears are only available for the failure modes of surface fatigue pitting, tooth bending fatigue, scuffing, and tooth yielding.

9.1.1 Pitting resistance and bending strength

Gear rating shall be in accordance with ISO 6336 series. Miner's rule shall be applied in accordance with ANSI/AGMA ISO 6336-6-A08 to calculate safety factors using the load spectrum supplied by the wind turbine manufacturer. Life factors, Z_{NT} and Y_{NT} at the load cycle number, N_L , shall be determined using the curve(s) intersecting at 0.85 at 10^{10} cycles using a log-log relationship. Pitting and bending fatigue lives shall be a minimum number of hours specified by the wind turbine manufacturer but not less than the specified design life.

$K_{H\beta}$ and $K_{F\beta}$ values shall be calculated for each load bin. These values shall be used in the Miner's rule calculation.

The minimum stress safety factor for pitting resistance shall be $S_H = 1.25$. The minimum stress safety factor for bending strength shall be $S_F = 1.56$.

9.1.2 Scuffing

Scuffing calculations are based on Blok's total contact temperature (flash temperature) method and the integral temperature (bulk temperature) method.

ISO/TS 6336-20 and AGMA 925 are based on the total contact temperature method and yield similar results although ISO/TS 6336-20 provides a safety factor and AGMA 925 provides a percentage of risk.

Evaluation of scuffing shall be performed using either the ISO/TS 6336-20 or AGMA 925 method. The maximum value for the risk of scuffing is 5% for AGMA 925. The minimum safety factor for ISO/TS 6336-20 is 1.3. Scuffing rating shall be performed at the maximum operating load and rated speed. The gear bulk and gear mesh temperatures shall be calculated at rated load and rated speed and at the highest gearbox operating temperature at which the turbine controller either reduces power production or shuts down the turbine.

Time series from DLC for ultimate load analysis should be scanned for sequences where the torque exceeds the maximum operating load for a duration that could be sufficient to cause scuffing. If such events occur, this load level should be used in the scuffing rating.