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Wind turbines —

Part 4: Design and specification of gearboxes

Aérogénérateurs —

Partie 4: Conception et spécifications des boîtes de vitesses

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 81400-4 was prepared by AWEA and AGMA (as ANSI/AGMA/AWEA 6006-A03) and was adopted, under a special “fast-track procedure”, by Technical Committee ISO/TC 60, *Gears*, in parallel with its approval by the ISO member bodies.

ISO 81400 is part of the IEC 61400 series.

Introduction

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 the American Wind Energy Association (AWEA) and American Gear Manufacturers Association (AGMA) members representing international wind turbine manufacturers, operators, researchers, consultants; and gear, bearing, plus 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 superseded 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 (ANSI) on January 9, 2004.

Wind turbines - Part 4: Design and specification of gearboxes

1 Scope

This standard applies to gearboxes for wind turbines with power capacities ranging from 40 kW to 2 MW. It applies to all parallel axis, one stage epicyclic, and combined one stage epicyclic and parallel shaft enclosed gearboxes. The provisions made in this standard are based on field experience with wind turbines having the above power capacities and configurations.

Guidelines of this standard may be applied to higher capacity wind turbines provided the specifications are appropriately modified to accommodate the characteristics of higher capacity wind turbines.

Life requirements apply to wind turbines with a minimum design lifetime of 20 years.

2 Normative references

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

AGMA 901-A92, *A Rational Procedure for Preliminary Design of Minimum Volume Gears*

AGMA 913-A98, *Method for Specifying the Geometry of Spur and Helical Gears*

AGMA 925-A03, *Effect of Lubrication on Gear Surface Distress*

AMS 2301, *Aircraft quality steel cleanliness, magnetic particle inspection procedure*

ANSI Y12.3-1968, *Letter symbols for quantities used in mechanics of solids*

ANSI/AGMA 1012-F90, *Gear Nomenclature, Definitions of Terms with Symbols*

ANSI/AGMA 2101-D04, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*

ANSI/AGMA 6000-B96, *Specification for Measurement of Linear Vibration on Gear Units*

ANSI/AGMA 6001-D97, *Design and Selection of Components for Enclosed Gear Drives*

ANSI/AGMA 6025-D98, *Sound for Enclosed Helical, Herringbone, and Spiral Bevel Gear Drives*

ANSI/AGMA 6110-F97, *Standard for Spur, Helical, Herringbone and Bevel Enclosed Drives*

ANSI/AGMA 6123-A88, *Design Manual for Enclosed Epicyclic Metric Module Gear Drives*

ANSI/AGMA 9005-E02, *Industrial Gear Lubrication*

ASTM A534, *Standard specification for carburizing steels for anti-friction bearings*

Det Norske Veritas Classification AS, Classification Notes No. 41.2, *Calculation of Gear Rating for Marine Transmissions,* July 1993

DIN ISO 281 Bbl. 4:2003, *Dynamische Tragzahl und nominelle Lebensdauer - Verfahren zur Berechnung der modifizierten Referenzlebensdauer für allgemein belastete Wälzlager (Dynamic load ratings and life - Method for calculation of the modified reference rating life for generally loaded rolling bearings)*[1)]

DIN 743:2000, *Tragfähigkeitsberechnung von Wellen und Achsen (Calculation of load capacity of shafts and axles)*

DIN 6885-2:1967, *Drive Type Fastenings without Taper Action; Parallel Keys, Keyways*

DIN 7190:2001, *Interference fits - Calculation and design rules*

1) English translation available as ISO TC 4/SC 8 N254a

ISO 76:1987, *Rolling bearings - Static load ratings*

ISO 281:1990, *Rolling bearings - Dynamic load rating and rating life*

ISO R773:1969, *Rectangular or square parallel keys and their corresponding keyways (dimensions in millimeters)*

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

ISO 4406:1999 (SAE J1165), *Hydraulic fluid power - Fluids - Method for coding the level of contamination by solid particles*

ISO 6336- 1: 1996, *Calculation of load capacity of spur and helical gears- Part 1: Basic principles, introduction and general influence factors*

ISO 6336- 2: 1996, *Calculation of load capacity of spur and helical gears- Part 2: Calculation of surface durability (pitting)*

ISO 6336- 3: 1996, *Calculation of load capacity of spur and helical gears- Part 3: Calculation of tooth bending strength*

ISO 6336-5: 1996, *Calculation of load capacity of spur and helical gears- Part 5: Strength and quality of materials*

ISO/DIS 6336-6[2], *Calculation of load capacity of spur and helical gears - Part 6: Calculation of service life under variable load*

ISO 8579-1:2002, *Acceptance code for gears - Part 1: Determination of airborne sound power levels emitted by gear units*

ISO 8579-2:1993, *Acceptance code for gears - Part 2: Determination of mechanical vibration of gear units during acceptance testing*

ISO/TR 13593:1999, *Enclosed gear drives for industrial applications*

ISO/TR 13989-1:2000, *Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears - Part 1: Flash temperature method*

ISO 14104:1995, *Gears - Surface temper etch inspection after grinding*

ISO/TR 14179-1:2001, *Gears - Thermal capacity - Part 1: Rating gear drives with thermal equilibrium at 95 °C sump temperature*

3 Definitions and symbols

3.0 Terms and definitions

For the purposes of this document, the terms and definitions given in 3.2 through 3.4 and the following apply, wherever applicable, conforming to ANSI/ AGMA 1012-F90, and ANSI Y12.3-1968.

3.1 Symbols

The symbols, terms and units used in this standard are shown in table 1.

NOTE: The symbols and terms contained in this document may vary from those used in other AGMA standards. Users of this standard should assure themselves that they are using these symbols and terms in the manner indicated herein.

3.2 Wind turbine terms

active yaw: A system to rotate the nacelle relative to the changing direction of the wind. See passive yaw.

airfoil: Two dimensional cross section of a blade.

annual average wind speed: The time averaged, mean, horizontal wind speed for one calendar year at a particular site and a specified height.

annual average turbulence intensity: A measure of the short-time and spatial variation of the inflow wind speed about its long time average.

availability: The ratio of the number of hours that a turbine could operate to the total number of hours in that period, usually expressed as a percentage. Downtime due to faults or maintenance (scheduled or otherwise) generally make up the unavailable time.

bedplate: In a modular system, the structure that supports the drive train components and nacelle cover. Also called a main frame.

blade: The component of the rotor that converts wind energy into rotation of the rotor shaft.

brake: A device capable of stopping rotation of the rotor or reducing its speed.

certification: Procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements, also known as conformity assessment.

certification standard: Standard that has specific rules for procedures and management to carry out certification of conformity.

control system: A system that monitors the wind turbine and its environment and adjusts the wind turbine to keep it within operating limits.

[2] Presently at the development stage.

Table 1 - Symbols

Symbol	Term	Units	Where first used
C	Basic dynamic load rating	N	Eq 1
C_0	Basic static load rating	N	5.1.3.1
f_{ma}	Mesh misalignment	- -	5.1.1.3
K_A	Ratio between the equivalent and the nominal torque	- -	5.1.1.5
$K_{H\beta}$	Load distribution factor	- -	5.1.1.2
K_{lc}	Ratio of maximum contact pressure to contact pressure for line contact without misalignment	- -	Eq 4
K_m	Ratio of maximum contact pressure with misalignment to maximum contact pressure without misalignment	- -	Eq 4
K_v	Dynamic factor	- -	5.1.1.1
k	Load sharing factor for the maximum loaded roller	- -	Eq 2
L_{adv}	Combined advanced rating life	hours	5.1.3.2.3
$L_{adv,\,i}$	Advanced rating life on the ith load level	hours	Eq 5
L_{h10}	Basic rating life	hours	Eq 1
L_{we}	Effective roller length	mm	Eq 3
L_{10r}	Combined nominal reference rating life	hours	5.1.3.2.3
n	Rotational speed	rpm	Eq 1
P	Dynamic equivalent bearing load	N	Eq 1
P_o	Equivalent static bearing load	N	5.1.3.1
P_t	Rated power of wind turbine	kW	Eq 6
p	Exponent in bearing life equation	- -	Eq 1
p_{line}	Contact pressure for line contact	MPa	Eq 3
p_{max}	Maximum contact stress	MPa	Table 3
Q	Single roller maximum load for a clearance free bearing	N	Eq 2
Q_{ty}	Recommended oil quantity	liters	Eq 6
q_i	Time share on the ith load level	- -	Eq 5
Ra	Roughness average	μm	5.2.8.2
Rz	Mean peak-to-valley height	μm	5.2.8.2
S_F	Safety factor for bending strength	- -	5.1.1.4
S_H	Safety factor for pitting resistance	- -	5.1.1.4
Y_N	Stress cycle factor for bending strength	- -	5.1.1.4
Y_{NT}	Life factor for bending	- -	5.1.1.5
Z	Total number of rolling elements	- -	Eq 2
Z_N	Stress cycle factor for pitting resistance	- -	5.1.1.4
Z_{NT}	Life factor for pitting resistance	- -	5.1.1.5
α_0	Nominal contact angle of the bearing	degrees	Eq 2
$\Sigma\rho_{line}$	Curvature sum for line contact	- -	Eq 3
κ	Viscosity ratio	- -	5.1.3.3

cut-in wind speed: The minimum wind speed at hub height at which the control system calls for the turbine to produce power.

cut-out wind speed: The maximum wind speed at hub height at which the control system calls for the turbine to produce power.

damped yaw: A device used to slow yaw motions.

design life: The period of real time that the system is expected to continue functioning. Includes operating, idling and stopped time.

downwind turbine: A HAWT where the wind passes the tower before the rotor.

dynamic equivalent bearing load: A hypothetical load, constant in magnitude and direction, acting radially on radial bearings or axially on thrust bearings, which if applied, would have the same influence on bearing life as the actual loads to which the bearing is subjected.

emergency shutdown: A rapid shutdown of the wind turbine triggered by the control system, a protection system or manual intervention.

extreme load: The extreme load is that load from any source, either operating or non-operating, that is the largest single load that the gearbox will see during its design life beyond which the gearbox no longer satisfies the design requirements. This load can be either forces, moments, torques, or a combination of the three. This load, supplied by the wind turbine manufacturer, includes all partial load safety factors.

extreme torque: The extreme torque is that torque from any source that is the largest single torque that the gearbox will see during its design life beyond which the gearbox no longer satisfies the design requirements.

extreme wind speed: The highest short-term average wind speed that is likely to be experienced by the wind turbine during its service lifetime. It is typically based on statistical estimates of the long term behavior of the wind speed.

feathering: In a variable pitch HAWT, the action of pitching the blades to a minimum power production position.

fixed pitch rotor: A rotor with blades that do not change pitch during operation. The pitch angle of the rotor blades may be changed manually for site specific or seasonal wind spectrum changes.

free yaw: See passive yaw.

HAWT: Horizontal axis wind turbine. The rotational axis of the rotor is approximately parallel to the horizon.

horizontal axis: The axis of rotor rotation is approximately parallel to the horizon.

hub height: For a HAWT, the height to the center of the rotor.

hub: The structure that attaches the blades to the rotor shaft.

idling: Operating condition where the rotor is rotating and the generator is not producing power.

input or mechanical power: The mechanical power measured at the gearbox low speed shaft or the wind turbine rotor shaft.

input shaft: See rotor shaft.

integrated system: A system architecture in which the gearbox housing supports the rotor directly, and in some cases, the generator(s) and other components. See modular system.

lock: The use of a mechanical device to prevent movement of the rotor or yaw drive.

main frame: See bedplate.

main shaft: See rotor shaft.

maximum operating load: The maximum operating load is the highest load in the load spectrum.

maximum power: The highest level of net electrical power delivered by a wind turbine in normal operation.

Miner's sum dynamic equivalent bearing load: The dynamic equivalent bearing load obtained by combining loads and speeds in a wind spectrum using Miner's rule.

modular system: A system architecture in which the rotor shaft assembly, gearbox, generator(s) and, possibly, a yaw drive, are separate components mounted to a common main frame. See integrated system.

motoring: Operating condition where the generator is consuming power.

nacelle: The structure that contains the drive train and other components located at the top of a HAWT.

nacelle cover: The housing that covers the nacelle.

nominal speed: The gearbox low speed shaft speed at which mechanical power is defined.

non-rotating: Operating condition where the rotor is not rotating.

normal shutdown: Transitional operating condition where the rotor decelerates from operating speed to standstill or idling and the generator ceases to generate power.

operational wind speed range: The range of wind speeds between the cut-in and the cut-out speed.

output shaft: See high speed shaft.

parked: Operating condition where the rotor is not rotating because the parking brake is applied.

parking brake: A device capable of preventing rotor rotation.

passive yaw: The forces of the wind are used to align the nacelle (rotor disk) relative to the changing direction of the wind. See active yaw.

pitch: The angular position of the rotor blades about their long axis.

pitch control: Rotor shaft torque limiting is accomplished by actively adjusting the pitch.

preventive maintenance: Scheduled work intended to prevent failure or unscheduled repairs.

rated power: The continuous electrical power output assigned by the WTGS manufacturer that the wind turbine is designed to achieve under normal operating conditions at rated wind speed.

rated wind speed: The specified wind speed, assigned by the WTGS manufacturer, at which the rated power is produced.

rotor: The hub/blade assembly.

rotor bearing(s): The bearing(s) that supports the rotor shaft.

rotor diameter (horizontal axis): Diameter of the disk swept by the rotation of the blades.

rotor shaft: The shaft that supports the rotor and transmits the rotor torque to the gearbox. Also called the main shaft.

rotor speed: The rotational speed of the wind turbine rotor about its axis, in revolutions per minute.

stall control: Rotor shaft torque limiting is accomplished by aerodynamic design (airfoil selection, blade taper, blade twist, blade pitch, rotor speed).

standstill: See non-rotating.

startup: Transitional condition where the rotor accelerates from standstill or idling to operating speed and the generator begins to generate power.

tower: The structure that supports the nacelle in a HAWT.

turbulence intensity: A statistical measure of the variation in the wind speed. The ratio of the standard deviation of the wind speed to the mean wind speed.

upwind turbine: A HAWT where the wind passes the rotor before the tower.

variable pitch rotor: A rotor whose blade pitch can be varied during operation. The pitch angle may be actively controlled to optimize power or limit loads in response to the conditions.

variable speed: Rotor shaft torque limiting is accomplished by using high voltage electronic components and special generator designs to allow a wide range of rotor speeds. This method utilizes changes in inertial energy in the rotor to absorb the effect of wind gusts.

VAWT: Vertical axis wind turbine. The rotational axis of the rotor is approximately perpendicular to the horizon. This kind of turbine is beyond the scope of this standard.

wind turbine generator system (WTGS): A system that converts the kinetic energy of the wind into electrical power.

wind turbine manufacturer: Entity that designs, manufactures and warrants wind turbines.

wind turbine operator: Entity that operates and maintains wind turbines.

yaw: Rotation of a HAWT's nacelle about the long axis of its tower. Used to orientate the nacelle (rotor disk) with respect to the prevailing wind.

yaw bearing: The bearing system that supports the nacelle in a HAWT. It permits the nacelle to rotate about the tower axis.

yaw drive: The system of components used to cause yaw motion.

3.3 Gearbox terms

alloy steel: Steel containing significant quantities of alloying elements such as nickel, chrome, or molybdenum to improve its properties such as hardenability or toughness.

ambient temperature: The dry bulb air temperature within the immediate vicinity of the gearbox.

annulus gear: Gear wheel with teeth on the inner surface of a cylinder. Also known as an internal gear.

aspect ratio: The ratio of the pinion face width to the pinion operating pitch diameter.

bearing basic rating life: The life where adjustment factors for reliability, material and environment are taken as unity (1.0).

bearing manufacturer: Entity that designs, manufactures and warrants bearings for wind turbine gearboxes.

bulk oil: The oil that is most representative of the overall physical condition of the lubricant within the lubrication system. With splash lubricated gearboxes, the location of this lubricant is at or near the midpoint of the oil sump level shortly after the drive is shut down at operating temperature. With pressure fed lubrication systems, this is represented by the oil within the pressure line between the oil pump and filter assembly during system operation.

carburizing: A heat treatment process where gears are heated in a carbon rich atmosphere (usually gas carburizing) that causes carbon to diffuse into the surface layers of the gear teeth. The gears are hardened by either quenching from the carburizing temperature or they are cooled, reheated and quenched. The carburizing and hardening is followed by tempering where the gears are reheated to a relatively low temperature and slowly cooled.

coupling: A device that connects two rotating shafts to transmit power, accommodate misalignment, and compensate for axial movement.

double helical gear: Gear wheel with both right-hand and left-hand helices. The teeth are separated by a gap between the helices.

epicyclic: Gear arrangement consisting of multiple parallel axis gears including a sun pinion, several planets that mesh with the sun, planet carrier, and an annulus gear that meshes with the planets.

gear: Of two gears in a gearset, the one with the larger number of teeth is the gear. Also known as the wheel. See pinion.

gearbox: A complete assembly of gears, shafts, bearings, housing, seals, lubrication system and associated components.

gearbox manufacturer: Entity that designs, manufactures and warrants gearboxes for wind turbines.

gear ratio: The ratio of the larger to the smaller number of teeth in a pair of gears.

gearset: A pinion and gear that are intended to run together.

grinding notch: A discontinuity produced by a grinding tool between the start of active profile and tooth root that increases the tooth root stress.

helical gear: A gear with teeth that are inclined to the gear axis like a helical screw.

helix modification: A manufacturing modification of a pinion or gear obtained by changing the shape of the tooth flank along the face width.

high speed shaft: The highest speed shaft in a gearbox that drives the generator.

housing: The enclosure that contains the gearbox components such as gears, shafts, bearings and associated components.

inner ring: In a bearing, the material between the inside dimension of the roller/ball and the outside diameter of the part the bearing is mounted on.

involute profile modification: A manufacturing modification of a pinion or gear where a small variable amount of material is removed along the tooth profile in the root to tip direction.

low speed shaft: The lowest speed shaft in a gearbox. See rotor shaft.

lubricant manufacturer: Entity that designs, manufactures and warrants lubricants for wind turbine gearboxes.

module: The ratio of the pitch diameter in millimeters to the number of teeth in a gear.

nitriding: Heat treatment process where gears are heated in a nitrogen atmosphere that causes nitrogen to diffuse into surface layers of gear teeth and form hard nitrides. Distortion is small, because nitriding is done at low temperatures and there is no quench.

outer ring: In a bearing, the material between the outside dimension of the roller/ball and the bore of the part the bearing is mounted within.

parallel shaft: A gear arrangement where the pinion and gear mesh on parallel axes.

pinion: Of two gears in a gearset, the one with fewer number of teeth is the pinion. See gear.

planetary: An epicyclic gear arrangement where the annulus is fixed, the planets rotate about their own axes, and the planet carrier rotates.

power take-off (PTO): Additional output shaft for driving auxiliary equipment, such as oil pumps.

profile shift: A modification of a gear where the tooth profile is radially shifted.

protuberance cutter: A tool for cutting gear teeth that cuts a relief in the profile of the gear teeth to avoid grinding notches.

purchaser: Entity that issues purchase contracts for wind turbine gearboxes.

rim thickness: The radial distance from the roots of the teeth to the inner diameter of the rim or to the bore on an external gear, and to the outside diameter on an internal gear.

split power path: A gear arrangement consisting of multiple parallel axis gears. The arrangement is analogous to epicyclic gears except there is no annulus gear.

spur gear: Gear with teeth that are parallel to the gear axis.

star: An epicyclic gear arrangement where the annulus rotates, the planets (stars) rotate about their own axes, and the planet carrier is fixed.

through hardening: Heat treatment process where gear blanks are austenitized, rapidly quenched to obtain a predominantly martensitic microstructure, and tempered. Gear teeth are machined after through hardening to avoid distortion.

NOTE: Through hardening does not imply that the part has equivalent hardness throughout the entire cross-section.

torque arm: A structural component that attaches to the housing of a shaft mounted gearbox and prevents rotation of the gearbox about the rotor shaft.

wheel: Of two gears in a gearset, the one with the larger number of teeth is the wheel. Also known as the gear.

3.4 Filtration terms

cleanliness level: The cleanliness level as defined by ISO 4406 is a code system used to quantify the number of particles of a certain size in a given volume of oil. See annex F.

filter: A device for removing solid particles from a liquid stream, typically by means of porous media.

inline filter: A filter installed in the main oil circulation system that supplies gears and bearings with oil.

offline filter: A filtration device independent of the main lubrication system, typically with a separate pump, that operates continuously to improve oil cleanliness. Also called bypass filter, kidney loop filter, or side stream filter.

4 Design specification

4.1 Introduction

This clause provides the minimum required information for the specification of wind turbine gearboxes. It is important for the purchaser to identify what is expected of the gearbox manufacturer. A thorough specification is the method by which this is done. The scope of the specification may range from only performance and life requirements to detailed design and method of calculation requirements. If wind turbine certification is required, the purchaser shall clearly specify all certification documents relevant to the gearbox. The specification should contain the information noted in annex E.

4.2 Specification introduction

An introduction shall be provided that identifies the intent of the procurement specification. This shall include a description of the type of wind turbine, its basic modes of operation, the application of the gearbox in the wind turbine, and a description of the interfaces to the gearbox such as generator, rotor, bedplate, torque arm, lubricant system and accessories.

4.3 Gearbox configuration

4.3.1 Configuration

The general configuration of the gearbox shall be specified. This may include: the type of mounting; the type of gearing; the gear arrangement; the number of high speed shafts; the location and type of power take-off gears (PTO); and the method of lubrication.

All requirements for the geometric configuration of the gearbox shall be specified. This may include: the overall length, width, or height; the distance between shaft centers; length of shaft extensions; angle of shaft tilt or offset; gear housing split plane; the maximum weight, or other features.

A detailed description of all components interfaced to the gearbox shall be provided. Each interface shall be detailed for mounting, support and loading.

4.3.2 Rotor speed

The rotor speed, or speed range, shall be specified. This shall include expected speed during power production and idling mode. The direction of rotation for each of these situations shall be specified.

4.3.3 Gear ratio

The overall gear ratio and its tolerance shall be specified for the drive gears and any PTO gears.

The overall gear ratio of the gearbox is set by the requirements for rotor speed and generator speed. However, if there is more than one stage of gears, the gearbox manufacturer can select gear ratios for each stage to maximize load capacity and minimize weight (see AGMA 901-A92).

4.4 Loading

4.4.1 Description of loads

It is the responsibility of the wind turbine manufacturer to provide all loads applied to the gearbox to allow adequate evaluation of the design life requirements for all gears, bearings, shafts and the housing (see annex B). The details of this load description are presented in the following sections.

The loads should be thoroughly detailed in a load description document. This document should include:

- torque-frequency histogram including all operating loads;
- transient loads described as annotated time series. Refer to section B.5.2.2 and figure B.2 for a sample of an annotated brake event;
- torque-speed relationships; and
- other structural loads described in fatigue-based cycle counts at pertinent interfaces. These loads can be presented as a representative time series of the loads or the results of a Rainflow Count [1] with mean value, amplitude (peak-to-peak), and frequency of occurrence.

The purchaser shall indicate in the loads document the partial safety factors and load uncertainty factors used in deriving the loads. Any additional multipliers to be applied to the loads shall be explicitly stated. The source and rationale for the use of the safety factors or multipliers or both shall be described or sufficiently referenced.

4.4.2 Torque loads

4.4.2.1 Fatigue

The low speed shaft torque spectrum shall be specified in bins with:

- torque level;
- cycles or revolutions per torque level;
- nominal speed for design;
- idling speed.

It shall be clearly stated as to which portion of the turbine lifetime the spectrum refers.

For variable speed wind turbines, it may be necessary to separate each torque bin into several speed bins.

Specified torque level of each bin shall represent the highest level of torque represented in that bin. To avoid excessive conservatism, sufficient quantity of bins (at least 40) shall be used. Bin width need not be uniform, and, in fact, finer resolution at the highest torque bins is preferred. The load spectrum shall also contain one bin that accounts for idling and stopped time. The load spectrum total time will then match the design life of the turbine.

The torque spectrum shall include all fatigue loads, including all external transient loads such as brake loads, if applicable. If more than a single driven load, such as multiple generators, pump drives, or other PTO's exist, the torque spectrum for each driven load shall be defined.

4.4.2.2 Extreme torque loads

Extreme torque shall be specified by the wind turbine manufacturer:

- torque level;
- number of occurrences;
- source, such as rotor, generator or brake.

Extreme loads shall not be included in the load spectrum.

4.4.3 Structural loads

4.4.3.1 Non-torque load sources

In the case that the wind turbine rotor operation imparts non-torque loads to the gearbox low speed shaft, these loads shall be sufficiently described in the specification. Such loads may occur in any operating mode of the wind turbine including idling mode or when the turbine is parked. In modular arrangements the shafts are subjected to loads that need to be tolerated and transferred to the base mount (see A.5). Also, the generator, brake and other interfaced components can affect reaction loads on the gearbox and shafts. Such loads may occur in any operating mode of the wind turbine including idling mode or when the turbine is parked. These loads shall be sufficiently described in the specification. Stiffness in all loading directions of compliant supports, such as elastomeric bushings, shall be specified by the purchaser.

4.4.3.2 Structural fatigue loads

For each type of external load applied to the gearbox, fatigue loads shall be defined at the interface in a prescribed coordinate system as moments and forces in three directions.

Loads for each axis shall be defined in a spectrum, specified by bins, with:

- moment level;
- force level;
- cycles per revolution per moment/force level.

Multi-axis loads shall be provided in such a way that the phase relationship is preserved. The interpretation and use of data shall be a joint effort between the wind turbine manufacturer and the gearbox manufacturer.

4.4.3.3 Structural extreme loads

For each type of external loading to the gearbox, extreme loads shall be defined at the interface, in a prescribed coordinate system, with moments and forces in three directions.

4.4.4 Idling, parking and transient operation

Features such as duration and frequency of speeds and loads, method of lubrication, and temperature ranges during idling, parking and transient operation shall be specified.

4.4.4.1 Idling

Rotors should be allowed to idle whenever possible to avoid false brinelling, fretting corrosion, and corrosion on gear teeth, splines, bearing rollers and bearing raceways.

4.4.4.2 Parking

Parking should be minimized to avoid false brinelling, fretting corrosion, and corrosion on gear teeth, splines, bearing rollers, and bearing raceways. Dynamic loads on a parked wind turbine shall be specified in detail, for example, by an annotated time series.

4.4.4.3 Transient operations

Transient load events such as braking, cut-in, cut-out, generator shift, and blade pitch operations, shall be specified in detail, for example, by an annotated time series.

4.4.5 Dynamic loading

The loads specified by the purchaser shall include effects from the system's dynamics. Depending on the layout of the drive train and nacelle, the purchaser should quantify static and dynamic relative displacements of the different subsystems. The purchaser should also specify absolute movements and accelerations of the gearbox. Implementation of this dynamic analysis is a joint effort between purchaser and gearbox manufacturer. To enable the purchaser to perform the dynamic analysis during the development process, the gearbox manufacturer should supply general gearbox data, such as center of gravity, stiffness, inertia, damping, and clearances.

4.5 Certification

Wind turbines are usually certified to facilitate due diligence efforts and insurance requirements. All requirements for certification shall be described in the specification, including:

- name of classification society;
- standard or certification document name, number, and revision level;
- applicable section or paragraphs;
- any exceptions to the above documents.

Safety factors in excess of certification standard requirements shall be specified. It is the responsibility of the purchaser that the purchase specification is consistent with the relevant certification standards.

4.6 Operating environment

The expected operating environment of the gearbox shall be specified. As a minimum this shall include: the ambient temperature range, air temperature and air velocity across the gearbox, maximum relative humidity, extent of exposure to direct sunlight, precipitation and airborne particulates. See annex E for additional information on this subject.

4.7 Control and monitoring

Requirements for monitoring and control sensors associated with the gearbox shall be specified. This may include: lubricant level, temperature, pressure sensors, vibration sensors, filter bypass sensors, particulate accumulation sensors, or others.

4.8 Qualification testing

4.8.1 Prototype tests

Type and conditions of any qualification testing shall be specified. These tests shall be performed on a