Rules and Guidelines
IV Industrial Services

1 Guideline for the Certification of Wind Turbines

Edition 2010

This Guideline was compiled by Germanischer Lloyd in cooperation
with the Wind Energy Committee. The Wind Energy Committee consists of representatives from
public authorities, wind turbine and component manufacturers, engineering consultants,
institutes, universities, technical associations and insurance companies.
The current members of the Wind Energy Committee are named on our website:
www.gl-group.com/GLRenewables

This Guideline comes into force on 1st July 2010.

Interpretation of the Guideline is the exclusive prerogative of Germanischer Lloyd.
Any reference to the application of this Guideline is permitted only with the consent
of Germanischer Lloyd.

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List of Abbreviations

Abbreviation	**Meaning**
A	Abnormal (for partial safety factors)
C	Condition of the serviceability
CRP	Carbon Fibre Reinforced Plastic
Coh	Coherence function
DA	Design Assessment
DAA	Development Accompanying Assessment
DOF	Degree Of Freedom
DLC	Design Load Case
ECD	Extreme Coherent gust with Direction change
ECG	Extreme Coherent Gust
EDC	Extreme Direction Change
EOG	Extreme Operating Gust
EWM	Extreme Wind speed Model
EWS	Extreme Wind Shear
F	Fatigue
FEM	Finite Element Method
FRP	Fibre Reinforced Plastic
GRP	Glass Fibre Reinforced Plastic
GL	Germanischer Lloyd
GL Wind	Germanischer Lloyd WindEnergie GmbH
GL RC	Germanischer Lloyd Industrial Services GmbH, Renewables Certification
IPE	Implementation of design-related requirements in Production and Erection
LDD	Load Duration Distribution
N	Normal and extreme (for partial safety factors)
NTM	Normal Turbulence Model
NWP	Normal Wind Profile
PC	Project Certificate
QM(S)	Quality Management (System)
S	Wind turbine class S (S for special)
SWT	Small Wind Turbines
T	Transport, erection and maintenance (for partial safety factors and for the wind speed)
TC	Type Certificate
U	Ultimate limit state

Symbols and Units

Symbols and Units Used in the Guideline

Symbol	Meaning	Unit
A	cross-section area (strength) reference surface (aerodynamics)	m² -
A	category for the higher turbulence intensity	-
A_S	stress cross-section	m²
a	slope parameter	-
a_{ISO}	live modification factor	-
B	category for the lower turbulence intensity	-
b	width (breadth)	m
b_1	opening width (arc measure)	m
C	scale parameter of the Weibull function	m/s
C_A	coefficient of aerodynamic lift	-
C_W	coefficient of aerodynamic drag	-
C_M	coefficient of aerodynamic moment	-
C_{ia}	reduction factors for the material safety factor, short-term strength	-
C_{ib}	reduction factors for the material safety factor, fatigue strength	-
C_{ic}	reduction factors for the material safety factor, stability	-
C_{id}	reduction factors for the material safety factor, bonding	-
C_{IFF}	reduction factor for inter-fibre failure	-
c_{max}	maximum blade depth	m
c_{min}	parameter for calculating the ice formation on the blade	m
D	damage	-
D, d	diameter	m
D_Q	damage contribution from vortex-induced transverse vibrations	-
D_F	damage contribution of the actions from the operating conditions	-
d	nominal bolt diameter	m
E	E-modulus (modulus of elasticity)	MPa, N/mm²
F	force	N
F_i	force acting in the direction i = x, y or z	N
F_{Smax}	max. bolt force under extreme load	N
$F_{0,2min}$	bolt force at the 0.2 % elastic strain limit	N
f	line force	N/m
f	frequency	1/s
$f_{0,n}$	n-th natural frequency	1/s

Symbol	Meaning	Unit
f_R	maximum rotating frequency of the rotor in the normal operating range	1/s
$f_{R,m}$	transition frequency of the *m* rotor blades	1/s
G	gust reaction factor	-
G	dead weight	N
G	shear modulus	MPa, N/mm²
g	area load from dead weight	N/m²
g	acceleration due to gravity (=9.81m/s²)	m/s²
h	height	m
h_1	opening height	m
I	moment of inertia	m^4
I_{15}	characteristic value of the turbulence intensity for a mean wind speed of 15 m/s	-
j	casting quality level	-
j_0	constant	-
K	modified Bessel function	-
K_A	application factor	-
$K_{B\alpha}$	transverse load factor, scuffing	-
$K_{B\beta}$	face load factor, scuffing	-
$K_{F\beta}$	face load factor, root stress	-
$K_{F\beta}$	face load factor, root stress	-
$K_{H\alpha}$	transverse load factor, contact stress	-
$K_{H\beta}$	face load factor, contact stress	-
K_v	dynamic factor	-
K_γ	load distribution factor	-
k	flange gaps	m
k	shape parameter of the Weibull function	-
k_s	reduction factor for the design S/N curve of large bolts	-
L	isotropic, integral turbulence scale parameter	m
L_{10mr}	combined modified rating live	-
L_e	scale parameter of the coherence function	m
L_k	integral length parameter of the speed component	m
l	component length	m
l	statically effective span	m
M	moment	Nm
M_{Bmin}	minimum required braking moment	kNm
$M_{BminAusl}$	minimum design braking moment	kNm
M_{Bmax}	maximum actual braking moment	kNm

Symbol	**Meaning**	**Unit**
M_i	moment acting in the direction i = x, y or z	Nm
M_k	tilting moment of the induction generator	Nm
M_n	rated torque	Nm
m	mass	kg
m	slope parameter of the S/N curve	-
N	permissible load cycle number	-
N	perpendicular force (axial force)	N
N	recurrence period for extreme conditions	a
N_i	tolerable number of stress cycles	-
N_D	limiting stress cycle number – fatigue limit	-
n	quantity (i.e. number of)	-
n	rotational speed	1/min
n_1	minimum operating rotational speed	1/min
n_2	set value of the speed controller	1/min
n_3	maximum operating rotational speed	1/min
n_4	cut-out speed	1/min
n_A	activation speed	1/min
n_i	number of existing stress cycles	-
n_{max}	maximum overspeed	1/min
n_r	rated speed	1/min
n_{ref}	reference load cycle number	-
N	total number or revolutions	-
p	bearing exponent	-
p_{max}	maximum contact stress	N/mm^2
P	confidence level	-
P	live load	N
P	power	W
P	dynamic bearing load	N
$P_Ü$	survival probability	-
P_A	activation power	kW
P_r	rated power	kW
$P_R (V_{hub})$	Rayleigh probability distribution, i.e. the probability that $V < V_o$	-
P_T	over-power	kW
$P_W (V_{hub})$	Weibull probability distribution	-
p	area live load	N/m^2
Q	total load	N
q	area loading	N/m^2

Symbol	Meaning	Unit
q_i	time share on the i-th load level	-
R	resistance	N, Nm, MPa
R	stress or strain ratio	-
R, r	radius	m
Ra	arithmetic surface roughness	µm
S	action	N, Nm, MPa
S_d	reduction factor – casting quality	-
S_{ints}	safety factor for scuffing (integral temperature method)	-
S_B	safety factor for scuffing (flash temperature method)	-
S_F	safety factor for tooth breakage	-
S_H	safety factor for pitting	-
$S_{Pü}$	reduction factor – survival probability	-
S	safety	
$S_1(f)$	power spectral density	m²/s²
S_λ	safety factor for micropitting	-
s_K	tilting slip of the induction generator	-
T	temperature	°C, K
T	time interval	s
T	characteristic gust shape duration	s
t	component thickness	m
t	time (as a variable)	s
T_1	time constant of the stator	s
U_i	i% fractile value of the normal distribution	-
u	displacement in the x direction	m
V	thrust	N
V	wind speed	m/s
V (y, z, t)	longitudinal component of the wind speed, describing the horizontal wind shear	m/s
V (z)	magnitude of the wind speed at the height z	m/s
V (z, t)	longitudinal component of the wind speed in relation to height and time	m/s
V_A	short-term cut-out wind speed	m/s
V_{ave}	annual average wind speed at hub height	m/s
V_B	gust value	m/s
V_{cg}	extreme value of the wind speed amplitude for the coherent gust shape over the swept rotor area, applying the extreme coherent gust	m/s

Symbol	Meaning	Unit
V_{eN}	expected extreme wind speed (averaged over 3 s), with a recurrence period of N years. V_{e1} and V_{e50} for 1 or 50 years respectively, applying the steady-state extreme wind speed model	m/s
V_{gustN}	maximum value of the wind speed for the extreme operating gust, with an expected recurrence period of N years	m/s
V_{hub}	10-min mean of the wind speed at hub height	m/s
V_{in}	cut-in wind speed	m/s
V_N	expected extreme wind speed (averaged over 10 min), with a recurrence period of N years. V_1 and V_{50} for 1 or 50 years respectively, applying the turbulent extreme wind speed model	m/s
V_{out}	cut-out wind speed	m/s
V_r	rated wind speed	m/s
V_{ref}	reference wind speed: fundamental parameter of the extreme wind speed, used for definition of the type classes	m/s
V_T	the 10-min mean of the wind speed at hub height, specified by the manufacturer for maintenance, erection and transport. V_T can consist of several quantities.	m/s
v	coefficient of variation	-
v	displacement in the y direction	m
W	section modulus of a plane	m^3
w	displacement in the z direction	m
X''_d	subtransient reactance	-
x; x’	coordinates	m
y	parameter for the extreme wind shear model: horizontal distance to the hub centreline	-
y; y’	coordinates	m
Y_{NT}	live factor (tooth breakage)	-
z	height over terrain surface	m
z	number of teeth	-
z_{hub}	hub height of the wind turbine over ground level	m
z; z’	coordinates	m
Z_{NT}	live factor (pitting)	-
α	power law exponent for the normal wind profile	-
α_S	inclination of the outer flange surfaces	°
β	parameter for the models of extreme op erating gust, extreme direction change and extreme wind shear	-
Γ	gamma function	-
γ	slip	-
γ_F	partial safety factor for the loads	-

Symbol	Meaning	Unit
γ_{Gr}	partial safety factor for the analysis of the safety against bearing capacity failure	-
γ_{M}	partial safety factor for the material	-
γ_{M0}	material partial safety factor	-
γ_{Ma}	material partial safety factor for short-term strength	-
γ_{Mb}	material partial safety factor for fatigue strength	-
γ_{Mc}	material partial safety factor for stability	-
γ_{Md}	material partial safety factor for bonding, short-term strength	-
γ_{Me}	material partial safety factor for bonding, long-term strength	-
$\gamma_{M,3}$	material partial safety factor for the analysis of shear-loaded connections	-
γ_{P}	partial safety factor for the analysis of pile foundations	-
γ_{iT}	load partial safety factor for the rotor blade test	-
δ	opening angle	°
δ_{B}	logarithmic decrement	-
ε	strain	-
ε	nonlinear notch strain	-
Θ_{cg}	greatest angular deviation during a gust development from the direction of the average wind speed, applying the model for extreme coherent gust with direction change	°
$\Theta(t)$	time curve of the wind direction change	°
Θ_{eN}	extreme direction change, with a recurrence period of N years, applying the model of the extreme direction change	°
$\Theta_{N(t)}$	time curve of the extreme direction change with a recurrence period of N years, applying the model of the extreme direction change	°
Θ	temperature	°C
$\Theta_{\text{mean, year}}$	annual average temperature	°C
$\Theta_{\text{1year min/max}}$	extreme temperature with a recurrence period of 1 year	°C
$\Theta_{\text{min/max, operation}}$	extreme temperature for operation	°C
Λ_{1}	turbulence scale parameter	m
μ	friction coefficient / slip factor	-
μ_{E}	parameter for calculating the ice formation on the rotor blade	kg/m
ρ	density	kg/m³
ρ_{E}	density of the ice	kg/m^3
σ	normal stress	MPa, N/mm²
σ	nonlinear notch stress	MPa, N/mm²

Symbol	**Meaning**	**Unit**
σ_a	Stress amplitude	MPa, N/mm^2
$\Delta\sigma_A$	reference value of the S/N curve	MPa, N/mm^2
$\Delta\sigma^*_A$	reference value of the S/N curve	MPa, N/mm^2
$\Delta\sigma_D$	fatigue limit	MPa, N/mm^2
σ_k	linear-elastic notch stress	MPa, N/mm^2
σ_{lim}	Limiting stress	MPa, N/mm^2
σ_m	Mean stress	MPa, N/mm^2
σ_S	structural or hot spot stress	MPa, N/mm^2
σ_1	standard deviation of the longitudinal wind speed at hub height	m/s
$\Delta\sigma_i$	stress range	MPa, N/mm^2
τ	shear stress	MPa, N/mm^2
Φ	inclination of the plane	°
φ	yaw error	°
Φ	angle for two-phase short circuit	°
φA	cut-out yaw error	°
ω	angular velocity	1/s
Ωg	grid angular frequency	1/s
1P, 2P, 3P...	excitation of the wind turbine through the rotor speed multiplied by the factor 1, 2, 3...	1/s

Subscripts

Symbol	Meaning	Remarks
A	amplitude	
c	pressure	separated by a comma ($\sigma_{Sd,c}$)
d	design value	
F	load, action	
F	tooth root	
i	enumeration	
k	characteristic quantity	
M	material, mean value	e.g. γ_M, ε_M
max	maximum	
min	minimum	
p	prestress	separated by a comma ($\sigma_{Rd,p}$)
R	resisting	preceding in combination with the subscripts k and d, but without separation by a comma (e.g. σ_{Rd} or ε_{Rk})
res	resulting	
S	acting	preceding in combination with the subscripts k and d, but without separation by a comma (e.g. F_{Sd} or M_{Sk})
t	tension	separated by a comma ($\sigma_{Rd,t}$)
x; x’	coordinate designation	
y; y’	coordinate designation	
z; z’	coordinate designation	

Auxiliary Symbols

Symbol	Meaning
$\bar{}$	mean value of the overlined quantity

Prefixes

Symbol	Meaning
Δ	difference or part of the subsequent quantities
Π	product of the subsequent quantities
Σ	sum of the subsequent quantities

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1 General Conditions for Approval

Edition 2010

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Appendix 1.I

1.1 Scope

1.1.1 General

(1) This Guideline applies to the design, approval and certification of wind turbines, also known as wind energy conversion systems.

(2) The present Guideline represents a completely revised and expanded version of the “Guideline for the Certification of Wind Turbines” of Germanischer Lloyd, Edition 2003 with Supplement 2004.

(3) When carrying out certification, the overall concept of the wind turbine is assessed. The certification covers all component elements of the installation, i.e. safety as well as design, construction, availability, workmanship and quality are checked, assessed and certified.

(4) The actual operating life of a wind turbine can deviate from the design lifetime, and will in general be longer. For wearing parts and for coolants, oils and lubricants that do not attain the design lifetime of the wind turbine, the manufacturer of the wind turbine shall prescribe regular replacement intervals.

(5) Additional information and requirements for small wind turbines can be found in the Appendix 1.H.

(6) Certification of a wind turbine on the basis of this Guideline is carried out by Germanischer Lloyd Industrial Services GmbH, Competence Centre Renewables Certification (GL) with regard to the items specified in Section 1.2.

Note:

In the design of the wind turbine, aspects of occupational health and safety can be taken into account through compliance with the standard DIN EN 50308 “Wind turbines – Protective measures - Requirements for design, operation and maintenance”. National requirements shall be observed in all cases.

1.1.2 Transition periods

(1) For the application of this Guideline, the following transition periods shall apply after it comes into force, during which the GL “Guideline for the Certification of Wind Turbines”, Edition 2003 with Supplement 2004, may still be applied:

- 1 year for new wind turbines or wind farms
- up to 5 years for modifications to the design of wind turbines that were already assessed or certified by GL according to the GL Guideline, Edition 2003 with Supplement 2004, after consultation with GL.
- up to 5 years or for two times of re-certification on expiry of the validity of a Type Certificate according to the GL Guideline, Edition 2003 with Supplement 2004, issued by GL.

(2) In the case of new turbine types or modifications, the transition period shall only be applied if all documents needed for the requested extent of certification are submitted during the transition period.

(3) The application of editions of the GL Regulations that are older than the Edition 2003 with Supplement 2004 is no longer admissible at all.

1.1.3 Deviations

(1) Deviations from this Guideline are, without exception, permitted only with the consent of GL.

(2) The certification may in individual cases involve inclusion of locally applicable regulations and codes.

(3) The level of safety set by this Guideline shall be observed as a minimum requirement, even if national or regional laws or regulations require less.

(4) In the case of designs to which this Guideline cannot be applied, GL reserves the right to proceed in the spirit of the Guideline.

(5) If analysis concepts of different standards are to be applied, these shall generally not be mixed.

1.1.4 National and international requirements

(1) In general, this Guideline covers the national requirements in the aspects mentioned in this Guideline. Comments and requirements for certain countries can be found in the Appendices 1.A, 1.B, 1.C, 1.D, 1.E, 1.F and 1.G.

(2) When developing a wind turbine or project, locally applicable regulations and standards shall be considered in respect to national laws. The scope of this Guideline forms the requirements for the certification of a wind turbine or project.

(3) A regularly updated list of international grid codes can be found at the following web page: http://www.gl-group.com/pdf/IGCC_list.pdf

(4) An overview of the international standards, technical guidelines and specifications of the IEC and CENELEC with regard to wind turbines is given in Appendix 1.I.

1.1.5 Further Guidelines of GL

(1) In addition to this Guideline, GL has issued the following guidelines for certification of wind turbines:

- Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 1 – Wind Energy, 12 - Guideline for the Continued Operation of Wind Turbines, Edition 2009
- Germanischer Lloyd Rules and Guidelines, IV – Industrial Services, Part 4 – Guideline for the Certification of Condition Monitoring Systems for Wind Turbines, Edition 2007

(2) These guidelines can be applied optionally and in supplement to this Guideline as a basis for the certification of wind turbines or condition monitoring systems for wind turbines.

1.1.6 Technical Notes of GL

(1) Furthermore GL has issued the following technical notes for certification of wind turbines:

- GL Wind Technical Note 065 (TN 65): Grid Code Compliance according to Grid Codes (GCC), Certification procedure
- GL Wind Technical Note 066 (TN 66): Grid Code Compliance according to Grid Codes (GCC), Low Voltage Ride Through (LVRT), Test procedure
- GL Wind Technical Note 067 (TN 67): Certification of Wind Turbines for Extreme Temperatures (here: Cold Climate), Scope of Assessment
- GL Wind Technical Note: Certification of Fire Protection Systems for Wind Turbines, Certification Procedures
- GL Wind Technical Note: Certification of Organisations Performing Service Activities in the Wind Energy Industry, Scope of Assessment

(2) The technical notes can be applied optionally and in supplement to this Guideline as a basis for the certification of wind turbines on the subjects covered therein.

(3) The technical notes will be revised at short notice independently of the editions of this Guideline. The latest revision of the technical notes applies.

1.1.7 Assessment documents

(1) Texts in assessment documents shall be worded in German or English. Relevant excerpts of cited documents that are not generally known shall be appended to the assessment documents.

(2) At least the following information should be given on the cover sheet of each assessment document:

- title
- author
- company name of the author
- date
- revision index
- number of pages
- signature(s)

(3) On each page of the assessment document, at least the page number and the revision index of the document should be given.

(4) Further information on the documentation needed is given in the respective chapters and will be provided by GL on request.

1.2 Extent of Certification

1.2.1 Subdivision of the certification

(1) The following sections define the scope for Type Certification of a wind turbine (see Section 1.2.2) and for Project Certification of a wind turbine or a wind farm (see Section 1.2.3) and the steps necessary for certification.

(2) Prior to the complete design assessment within the scope of the Type Certification, the C- or D-Design Assessment for prototypes or a new turbine design can be issued optionally (see Section 1.2.2.3).

(3) Component certification (Design Assessment and Type Certification) of components such as listed in Section 1.2.2.5.3, para 4 may be performed analogously by application of the elements and modules as listed in this Guideline. The respective chapters of this Guideline shall be covered.

1.2.2 A- and B-Type Certificate for the type of a wind turbine

1.2.2.1 General

(1) Type Certification shall confirm that the wind turbine type is designed according to a wind turbine class in conformity with the design assumptions based on this Guideline and other technical requirements. It shall also confirm that the manufacturing process, component specifications, inspection and test procedures and corresponding documentation of the components covered by this Guideline are in conformity with the design documentation.

(2) To attain the A- or B-Type Certificate, the following steps are necessary; see Fig 1.2.1. The A- or B-Type Certificate applies only for a type of wind turbine, not for actual installations or projects.

- A- or B-Design Assessment (see Section 1.2.2.4)
- implementation of the design-related requirements in production and erection (IPE; see Section 1.2.2.5)
- quality management system of the manufacturer (see Section 1.2.2.6)
- prototype testing (see Section 1.2.2.7)
- Final Assessment (see Section 1.2.2.8)

(3) Following completion, GL will issue Statements of Compliance on the A- or B-Design Assessment, the quality management system, the implementation of the design-related requirements in production and erection and on the prototype testing as well as the Type Certificate.

(4) Analogously to A- and B-Design Assessments, A- and B-Statements of Compliance may be issued for the other subjects, where a B-Statement stands for a provisional statement. One or more B-Statements lead to a B-Type Certificate, which is a provisional Type Certificate.

1.2.2.2 Scope and validity

(1) The B-Type Certificate may contain one or more B-Statements as well as other items that are still outstanding, providing these are not directly safety-relevant. The B-Type Certificate has a validity period of one year. During the validity period, all installed wind turbines of this type shall be reported quarterly to GL.

(2) The final or A-Type Certificate is only issued if there are no outstanding items. It has a validity period of five years and will be updated annually.

(3) For the annual update, the following documents shall be submitted for evaluation by GL:

a) list of all modifications to the design of components forming a part of the design assessment or IPE and, if applicable, documents for evaluation of the modifications (see Tables 1.2.1 and 1.2.2 for examples)

b) list of all installed wind turbines of the type (at least a statement of the type with precise designation of the variant, serial number, hub height, location)

c) list of all damages to components of the installed wind turbines forming a part of the design assessment or IPE (see Tables 1.2.1 and 1.2.2 for examples)

d) declaration on possible changes or additions to workshops and / or store-houses (see Section 1.2.2.5.4, para 8)

(4) The Type Certificate will already lapse before the five years have expired if the A-Design Assessment, the certificate for the quality system or other parts of the Type Certificate are no longer valid.

(5) Upon expiry of the validity period, re-certification will be performed on request of the manufacturer (see Section 1.2.2.9).

Table 1.2.1 Examples for modifications or damages to be reported

Rotor blade	*Cracks in the laminate and adhesive*	*- list of damages* *- root cause analysis*
Planet carrier of main gearbox	*Change of material*	*- list of modifications* *- changed documentation*
Bolted connection of hub/rotor shaft (multiple bolt connection)	*Change in number of bolts*	*- list of modifications* *- changed documentation*

Table 1.2.2 Examples for modifications or damages not necessarily to be reported

Cover of main shaft	*Change of material*	-
Fixture for control cabinet	*Broken once*	-
Bolted connection of tower platform	*Change in size of bolts*	*- depending on scope of certification (see Note in Section 1.1.1)*

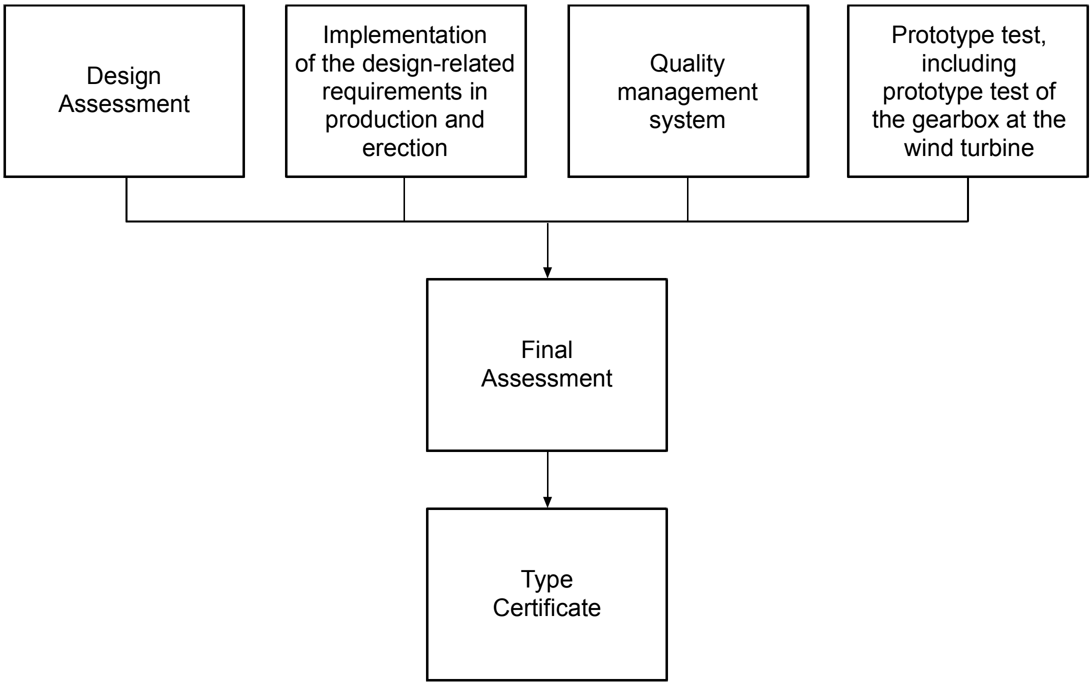

Fig. 1.2.1 Elements of the Type Certificate

1.2.2.3 C- and D-Design Assessment

1.2.2.3.1 General

(1) To attain the C- or D-Design Assessment for prototypes or a new turbine design, it is necessary that a plausibility check of the prototype be performed on the basis of the design documentation. Following completion, GL will issue a Statement of Compliance for the C- or D-Design Assessment.

(2) The C-Design Assessment (prototype assessment, in German: "Prototypengutachten") is used to erect the prototype of a wind turbine. As a rule, power and load measurements shall be performed at the prototype, after which they shall be compared to the calculated values. Modifications to the control system are permissible, provided that the resulting loads do not change appreciably. The C-Design Assessment is usually based on a complete plausibility check of the loads, the rotor blades, the control and safety concepts, the safety system, the machinery components as well as of the electrical installations and the tower and foundation. National or local regulations may require that the tower and foundation be subjected to a complete analysis.

(3) The D-Design Assessment is used to document the pre-review of a turbine design. It is not intended to be used for turbine manufacture. The D-Design Assessment is usually based on a complete plausibility check of the loads, the rotor blades, the control and safety concepts, the safety system, the machinery components, the electrical installations as well as of the tower.

1.2.2.3.2 Scope and validity

(1) For each type of wind turbine, only one C- or D-Design Assessment is produced. If a wind turbine type is modified with other rotor blades, a different operating mode or in other points strongly influencing the loads, then these are reasons which justify another prototype and another C- or D-Design Assessment.

(2) The Statement of Compliance for the C-Design Assessment is valid for test operation of the prototype comprising a maximum of 2 years or a maximum production equivalent to 4000 equivalent hours at full load operation. The criterion met first shall apply. By this time at the latest, a Statement of Compliance for the A- or B-Design Assessment shall exist for the wind turbine.

(3) The Statement of Compliance for the D-Design Assessment is valid for 2 years. Before the end of that period, a Statement of Compliance for the A- or B-Design Assessment shall exist.

1.2.2.3.3 Documents to be submitted

(1) For the D-Design Assessment, the following documents shall be submitted; further documents may be necessary e.g. in case of new concepts:

a) general description of the wind turbine including energy conversion concept (generator – converter – system)

b) listing of the primary components to be used (e.g. main bearing, gearbox, brake, generator, converter etc.)

c) description of the control and safety concepts

d) description of the safety system and the braking systems

e) description of the electrical installations, at least inside the hub, nacelle and tower (components, rating range and single line diagram)

f) concept of the lightning protection system

g) results of the complete load assumptions: extreme load tables and equivalents load tables (see also Chapter 4, Appendix 4.B, Tables 4.B.1 and 4.B.2). Further, an analysis of the maximal rotor speed, the maximal blade deflection and a Campbell diagram shall be submitted.

h) main drawings of the rotor blade, including structural design and blade connection

i) general arrangement drawing of the nacelle

j) drawings of the hub, main shaft and the main frame

k) main drawings of the gearbox

l) data sheets of the main electric components

m) main drawings of the tower

(2) For the C-Design Assessment, the following documents shall be submitted in addition to the documents necessary for the D-Design Assessment (see para 1):

a) main drawings of the foundation

b) soil investigation report

c) name and address of the owner

d) planned location of the prototype

e) 10-min mean of the extreme wind speed at hub height with a recurrence period of 50 years and the mean air density for the planned location of the prototype

f) test report for the arc resistance test of medium-voltage switchgear

(3) In certain cases, further documents may be necessary for C- or D-Design Assessment:

a) calculation documents for load assumptions

b) calculation documents for the tower

c) calculation documents for the foundation (for C-Design Assessment only)

1.2.2.3.4 Scope of assessment

(1) With regard to the safety system of the wind turbine, it is checked whether the safety-relevant operating values are sensed and made available to the safety system. Furthermore, the existence of two independent braking systems is checked.

(2) The blade root, hub and tower head loads to be submitted are checked for plausibility. This is possible if the extreme loads and fatigue loads can be compared with those of other wind turbines of similar size. If a wind turbine of a larger wind turbine type is submitted for assessment, then the pertinent values shall be extrapolated with due consideration of the physical circumstances.

Note:

A complete examination of the loads can be waived, since modifications to the control system that influence the loads are permissible for a prototype.

(3) The design of the rotor blades, the machinery components in the drive train and the tower as well as the electrical installations are also checked for plausibility, if it is possible to apply the experience gained in the dimensioning and design of similar turbines.

(4) As already mentioned in Section 1.2.2.3.1, it may depend on local regulations or requirements as to whether a plausibility check of the tower and foundation is sufficient or whether a complete analysis is necessary fro the C-Design Assessment.

1.2.2.4 A- and B-Design Assessment of the type of a wind turbine

1.2.2.4.1 Scope and validity

(1) To attain the A- or B-Design Assessment, a complete examination of the design analyses with all required material and component tests is required, together with witnessing of the commissioning of one of the first wind turbines; see Fig. 1.2.2.

(2) Following completion, GL will issue a Statement of Compliance for the A- or B-Design Assessment.

(3) The B-Design Assessment may contain items that are still outstanding, providing these are not directly safety-relevant. The Statement of Compliance for the B-Design Assessment has a validity period of one year. During the validity period, all installed wind turbines of this type shall be reported quarterly to GL.

(4) The final or A-Design Assessment is only issued if there are no outstanding items. The Statement of Compliance for the A-Design Assessment is valid indefinitely. It becomes invalid when modifications are made without the consent of GL to the design of components which form part of the design assessment.

(5) The examination of a foundation is optional within the scope of the A- or B-Design Assessments.

1.2.2.4.2 Assessment of the design documentation

(1) For assessment of the design documentation, the manufacturer shall submit a full set of documents in the form of specifications, calculations, drawings, descriptions and parts lists. It is recommended that the documents for the implementation of design-related requirements in production and erection (see Section 1.2.2.5), which are to be submitted within the scope of Type Certification, also be submitted for examination within the Design Assessment.

(2) Initially, the documents which form the basis of the design are assessed; these are

– control and safety system concepts (Chapter 2)

– load case definitions / load assumptions (Chapter 4)

(3) Once these have been assessed, design assessment of the components and subassemblies listed below follows:

– safety system (Chapter 2)

– rotor blades (Section 6.2)

– mechanical structures (Sections 6.3, 6.5) including nacelle cover and spinner (Section 6.4)

– machinery components (Chapter 7)

– electrical installations, including lightning protection (Chapter 8)

– tower (Section 6.6) and, optionally, foundation (Section 6.7)

– manuals (Chapter 9): erection manual, commissioning manual, operating manual, maintenance manual

(4) Further information on the documentation needed is given in the respective chapters and will be provided by GL on request.

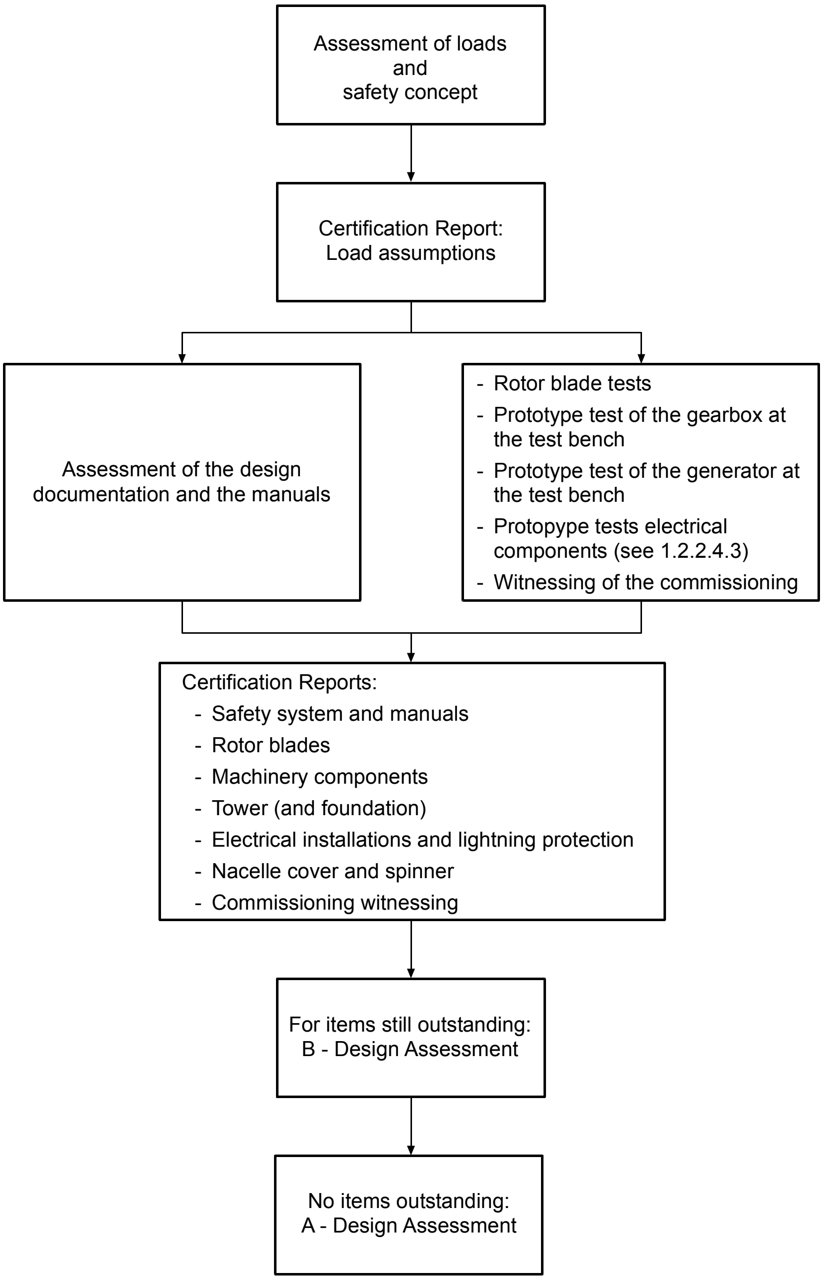

Fig. 1.2.2 Procedure for A- and B-Design Assessment

1.2.2.4.3 Tests and witnessing

The scope of the tests and witnessing within the scope of the Design Assessment is defined in Section 10.1.2 and generally comprises the following:

- blade tests
- prototype test of the main gearbox at the test bench
- prototype test of the generator together with the converter at the test bench
- type tests of the transformer
- prototype tests of the converter
- prototype tests of the medium-voltage switchgear
- tests for the lightning protection system
- witnessing of the commissioning

1.2.2.5 Implementation of the design-related requirements in Production and Erection (IPE)

1.2.2.5.1 Objective

It shall be ensured that the requirements stipulated in the technical documentation with regard to the components are observed and implemented in production and erection. This examination is based on the design, which was already assessed during the previous Design Assessment (Section 1.2.2.4). It is shown once only to GL by the manufacturer of the components and the wind turbine.

Note:
In the case of vendor inspections outside of the certification on the basis of an inspection specification established by the vendor, an individual scope shall be agreed on between the manufacturer and GL.

1.2.2.5.2 Quality management system

(1) The manufacturing assessment presupposes that manufacturer and supplier operate a quality system in conformance with the requirements for manufacturers of Section 3.1.

(2) Before IPE inspection begins, certain quality management (QM) requirements shall be met by the manufacturers. As a rule, the QM system should be certified as complying with ISO 9001, otherwise the QM measures will be assessed by GL. This will involve meeting the minimum requirements according to Section 3.2.3.

1.2.2.5.3 Critical manufacturing processes

(1) Additionally to QM requirements, the IPE assessment depends on quality assurance measures in production and erection. The necessary extent of such IPE assessment will be agreed upon in each individual case, and certified accordingly. On the basis of these measures and the components' design, the focal points or important / critical manufacturing processes (CMP) for IPE shall be derived.

(2) The descriptions of the CMP in production and in erection shall be presented in a summarizing document for the corresponding component and assembly. The assessment of the CMP shall be supported by means of drawings, specifications and record schemes for the individual processes, structures and components.

(3) It is recommended that the descriptions of the CMP already be submitted within the scope of the Design Assessment (see Section 1.2.2.4).

(4) For the components such as (insofar applicable)

- rotor blades
- blade bearings
- pitch drives
- rotor hub
- rotor shaft and axle journal
- main bearing
- main bearing housing
- gear box (incl. planet carrier and torque arm)
- brake
- couplings
- generator
- transformer
- converter
- main and generator frame
- blade-pitch, rotor and yaw locks
- yaw bearing
- yaw drives
- nacelle cover and spinner
- tower and (optionally) foundation
- bolted connections

that are important for the integrity of the wind turbine and also present a high danger potential for human health and life, an IPE assessment is required (at the component or wind turbine manufacturer's workshop; see Section 1.2.2.5.4, para 2). For the bolted connections playing a significant role in the transmission of forces, the standard of the quality measures shall be shown by a description of the CMP.

1.2.2.5.4 Scope and validity

(1) The implementation will be assessed by GL once during the production by a personal inspection within the scope of:

- verification that the design specifications are properly implemented in workshop drawings, workshop instructions, purchase specifications and installation instructions

- random inspection of the manufacturer's workshop

- random review of the material certificates

- random checks on the effectiveness of procedures for the acceptance of purchased components

- random checks of the fabrication processes

The focus of the random checks is on the CMP. The assessment requires manufacturing of at least one specimen representative of the type under certification.

(2) It shall be decided in each individual case whether the conformity can be inspected in the component manufacturer's workshop or as part of the incoming inspection of the wind turbine manufacturer. For a component (e.g. rotor blade or gear box) used in several wind turbines, an IPE assessment in course of a Component Certificate could be advantageous. In general for each workshop and/or store-house and/or erection site which has to be taken into account within IPE assessment, an individual Inspection Report will be issued which describes the fulfilment of IPE. Alternatively, in the case that the quality measures of the wind turbine manufacturer cover the supplier's quality measures, it may be sufficient to assess the IPE only at the wind turbine manufacturer in combination with random checks of suppliers. This shall be agreed upon with GL on beforehand.

(3) Changes in the manufacturing processes which influence the production quality or the component properties shall be reported to GL. In the event of major changes, the descriptive documents shall be submitted for renewed IPE assessment and, if necessary, a repeated personal inspection shall be made.

(4) GL reserves the right to extend the scope of IPE certification during production accordingly for special materials, production processes or components.

(5) In case of serious deviations within the IPE assessment, GL reserves the right to survey the adapted production process after implementation again or to monitor the production surveillance.

(6) If information is obtained on deviations or malfunctions in the operation of wind turbines that must be ascribed to production flaws, GL reserves the right to monitor the production also after the Type Certificate has been issued.

(7) The possibilities for rectifying faults are as follows:

- After revision of the descriptive documents, the defects that have occurred are remedied. A repeated personal IPE assessment may be necessary.
- If the defects are not detected, GL can impose external surveillance on the manufacturer for these components or assemblies.

(8) The Statement of Compliance for IPE is valid indefinitely. It becomes invalid when modifications are made without the consent of GL to the design, the production processes or the materials of components which formed part of the IPE as well as the design assessment. In addition, any changes to or addition of workshops and/or store-houses shall be declared by the wind turbine manufacturer.

1.2.2.5.5 Renewal of the Statement of Compliance for IPE

(1) In the event of changes affecting the Statement of Compliance for IPE, the renewal will be performed on request of the manufacturer. After completion of the process, GL issues a Statement of Compliance with a reference to the renewal.

(2) For the renewal, the following documents shall be submitted for evaluation by GL:

a) list of current manufacturing facilities
b) list of valid drawings, specifications and other documents
c) list of all modifications to the design and/or production and/or erection process of components forming a part of the IPE and, if applicable, documents for evaluation of the modifications
d) list of alterations to the QM system since the last audit or valid QM certificates of the production and/or erection units
e) list of all damages to the installed/produced components forming part of the IPE

(3) If modifications were made, these will be examined by GL.

(4) GL will review all Inspection Reports drawn up for the original Certification and decide whether additional actions are required. These actions could be:

- to repeat the surveillance due to critical processes that could make it necessary to survey them again.
- reassurance that necessary qualifications of personnel are still valid (e.g. approvals of welders)
- reassurance that necessary other approvals are still valid (e.g. shop approvals)

1.2.2.6 Quality management system

Within the scope of the quality management (QM) system, the manufacturer shall verify that he meets the requirements of ISO 9001 with regard to design and manufacture. As a rule, this is effected through the certification of the QM system by an accredited certification body (see Section 3.2).

1.2.2.7 Prototype testing

(1) The measurements within the scope of test operation of a prototype required for a new turbine type are defined in Section 10.1.1 and generally comprise the following points:

- measurement of the power curve
- measurement of the noise emission (optional)
- measurement of the electrical characteristics
- test of wind turbine behaviour
- load measurements
- test operation of the gearbox at the wind turbine

(2) Deviations from this measurement scope are only possible after agreement has been reached with GL.

(3) Details on the measurements are given in Chapter 10. On completion of the measurements, the activities listed in Section 10.1.1.1, para 5, shall be performed. If the results of the measurements are to be used as a basis for the strength analyses, additional requirements shall be coordinated with GL before the measurements are started.

(4) The Statement of Compliance for the Prototype Testing is valid indefinitely. It becomes invalid when modifications are made without the consent of GL to the design of components which influence measurement parameters included in the prototype testing.

1.2.2.8 Final Assessment

Prior to the issuing of the Type Certificate, all parts of the certification (Certification Reports, Inspection Reports, Statements of Compliance) will be checked for consistency and completeness with regard to the elements and modules described in this Guideline.

1.2.2.9 Re-certification

(1) Upon expiry of the validity period of the Type Certificate, re-certification will be performed on request of the manufacturer. After completion of the process, GL issues a Type Certificate (see Section 1.2.2.2) with a reference to the re-certification and a validity period of five years.

(2) For the re-certification, the following documents shall be submitted for evaluation by GL:

a) list of valid drawings and specifications

b) list of current manufacturing facilities

c) list of all modifications to the design of components forming a part of the Design Assessment or IPE and, if applicable, documents for evaluation of the modifications (see Tables 1.2.1 and 1.2.2 for examples)

d) list of alterations to the QM system since the last audit

e) list of all installed wind turbines of the type (at least a statement of the type with precise designation of the variant, serial number, hub height, location)

f) list of damages to the installed wind turbines on all components included in the Design Assessment (see Tables 1.2.1 and 1.2.2 for examples)

(3) For the re-certification, the process of Renewal of IPE (Section 1.2.2.5.5) shall be performed.

(4) If modifications were made to the structure, these are examined and a revision of the respective Statements of Compliance is issued.

1.2.3 A- and B-Project Certificate

1.2.3.1 General

(1) Project Certification shall confirm for a specific site that type-certified wind turbines meet requirements governed by site-specific external conditions and are in conformity with this Guideline, applicable local codes and other requirements relevant to the site. Within the Project Certification, it will be assessed whether the meteorological conditions, soil properties, and other environmental and electrical network conditions at the site conform to those defined in the design documentation for the wind turbine type.

(2) Project Certification shall also confirm that fabrication, transport, installation and commissioning are in conformity with GL Rules and Guidelines or other accepted standards and other technical requirements, and that the wind turbines are operated and maintained in conformity with the relevant manuals.

(3) To attain the A- or B-Project Certificate, e.g. for a wind farm or for a wind turbine, the following steps are necessary; see Fig. 1.2.3. The A- or B-Project Certificate applies for actual installations or projects.

- Type Certificate for the type of wind turbine used (see Section 1.2.2)
- assessment of site design conditions (see Section 1.2.3.3)
- Site-specific Design Assessment (see Section 1.2.3.4)
- examination of the foundation (see Section 6.7)
- surveillance during production (see Section 1.2.3.5)
- surveillance during transport and erection (see Section 1.2.3.6)

- surveillance during commissioning (see Section 1.2.3.7)
- Final Assessment (see Section 1.2.3.8)
- periodical inspection (Periodic Monitoring) to maintain the validity of the Project Certificate (see Section 1.2.3.9)

(4) Following completion, GL will issue Statements of Compliance on the modules mentioned above as well as the Project Certificate.

(5) Analogously to A- and B-Design Assessments, A- and B-Statements of Compliance may be issued for the other subjects. One or more B-Statements or a B-Type Certificate lead to a B-Project Certificate, which is a provisional Project Certificate.

1.2.3.2 Scope and validity

(1) The B-Project Certificate may contain a B-Type Certificate, one or more B-Statements as well as other items that are still outstanding, providing these are not directly safety-relevant. The B-Project Certificate has a validity period of one year.

(2) The final or A-Project Certificate is only issued if there are no outstanding items. The A-Project Certificate is valid until the end of the dedicated lifetime of the wind farm on the basis that

- Periodic Monitoring is carried out according to the inspection plan
- maintenance and repair is carried out according to the maintenance plan
- major modifications, conversions or repairs are performed with GL approval
- no unexpected malfunctions occur, based on the design or on bad assumptions about the external conditions

If the conditions are not fulfilled, GL reserves the right to require re-certification or to terminate the project certificate's validity.

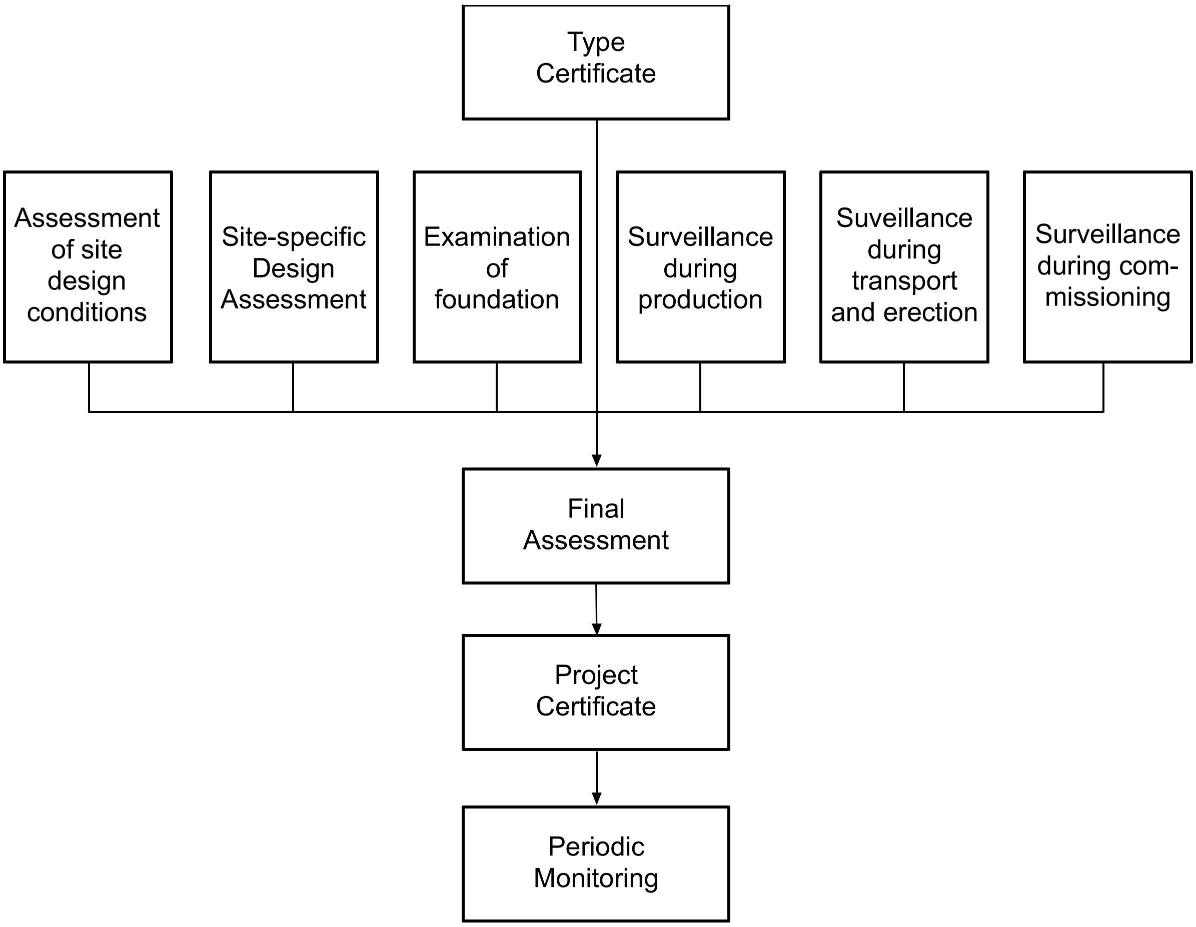

Fig. 1.2.3 Elements of the Project Certificate

1.2.3.3 Site design conditions

(1) The site design conditions include the examination of the environment-related influences on the wind turbine, and the mutual influence of a wind farm configuration.

(2) The following site design conditions have to be documented:

- wind conditions (Chapter 4)
- soil conditions (Section 6.7)
- influence of the wind farm configuration (Chapter 4)
- other environmental conditions, such as: salt content of the air, temperature, ice and snow, humidity, lightning strike, solar radiation etc. (Chapter 4)
- electrical grid conditions (Chapter 4, 8)

These site design conditions including reports on measurement results and further analyses will be assessed for plausibility, quality and completeness. The reports shall be provided by accredited measurement institutes.

1.2.3.4 Site-specific Design Assessment

(1) Based on the external conditions at the site, the Site-specific Design Assessment will take place subdivided into the following assessment steps:

- site-specific load assumptions (Chapter 4)
- comparison of site-specific loads with those from the Design Assessment
- site-specific support structure (tower and foundation) (Chapter 3, 5, 6)
- modification of the machinery components and rotor blades in relation to Design Assessment, if applicable (Chapter 6, 7)
- stress reserve calculation for the machinery components and rotor blades, if load comparison indicates higher loads than considered in the Design Assessment of the wind turbine (Chapter 6, 7)

(2) During the assessment, it shall be shown that the wind turbine is suitable for the intended site and that the requirements for the structural integrity of the wind turbine are met with due consideration of the external conditions.

(3) For some locations, it may be necessary to consider the influence of the environment on the structural properties.

(4) For the erection of the turbines within a wind farm, the influence on the loads shall be determined.

(5) Verification of the structural integrity can be provided through a comparison of the loads calculated for the site with the loads used for the Design Assessment. It shall be shown that the loads and deflections occurring at the wind turbine are smaller for all relevant sections than those assumed within the Design Assessment. Here the corresponding partial load and material safety factors shall be observed. The scope of the comparison shall be determined in consultation with GL.

(6) If the loads are higher than assumed during the Design Assessment, the verification for certain components can be provided in consultation with GL in the form of residual safety analyses.

(7) It may become obvious during the Site-specific Design Assessment that, due to increased loads, a component needs to be modified or substituted. In this case, the certification of this component shall be performed.

1.2.3.5 Surveillance during production

(1) Before surveillance during production begins, certain quality management (QM) requirements shall be met by the manufacturers. As a rule, the QM system should be certified as complying with ISO 9001, otherwise the QM measures will be assessed by GL. This will involve meeting the minimum requirements according to Section 3.2.3.

(2) The extent and amount of the surveillance during production depends on the standard of the quality management measures, and shall be agreed with GL. In general, the following actions and approvals will be carried out by GL:

- inspection and testing of materials and components (for a listing of affected components, see Section 1.2.2.5.3, para 4).
- scrutiny of QM records, such as test certificates, tracers, reports
- surveillance of production, including storage conditions and handling, by random sampling
- inspection of the corrosion protection
- inspection of the electrical power system
- supervision of the final test

(3) The objective of the surveillance during production is to verify whether the manufactured parts, components and products are in compliance with

- the technical specifications agreed in a certain project
- the documents certified by GL (calculations, drawings, procedures etc.)

(4) At least 25 % of all components have to be surveilled by GL, whereas GL is obligated to follow up failures/deficits found during the surveillance. In case the requirements are not met, the amount of surveillance will be increased accordingly.

1.2.3.6 Surveillance during transport and erection

(1) Before work begins, an erection manual (see Section 9.1), which if necessary takes account of the special circumstances of the site, shall be submitted. This will be checked for compatibility with the assessed design and with the prevailing transport and erection conditions (climate, job scheduling etc.). Furthermore, a site plan showing the location of the wind turbine shall be submitted, together with plans of the electrical installation showing how the plant will be connected to the public grid.

(2) The extent and amount of GL's supervisory activity depends on the quality management measures of the firms involved in transport and erection. As a rule, GL will carry out the following activities:

- identification and allocation of all components to the wind turbine in question
- checking the components for damage during transport
- inspection of the job schedules (e.g. for welding, installation, bolting up)
- inspection of prefabricated subassemblies, and of components to be installed, for adequate quality of manufacture, insofar as this has not been done at the manufacturers' works
- surveillance of important steps in the erection on a random-sampling basis
- inspection of bolted connections, surveillance of non-destructive tests (e.g. welded joints)
- inspection of the corrosion protection
- inspection of the electrical installation (run of cables, equipment earths and earthing system)

(3) At least 25 % of the transportation and erection of the wind turbines have to be surveilled by GL, whereas GL is obligated to follow up damages. In case the requirements are not met, the amount of surveillance will be increased accordingly.

1.2.3.7 Surveillance during commissioning

(1) Surveillance during commissioning is to be performed for all wind turbines of the wind farm and shall finally confirm that the wind turbine is ready to operate and fulfils all standards and requirements to be applied.

(2) Before commissioning, the commissioning manual (see Section 9.2) together with all the tests planned shall be submitted for assessment. Before commissioning, the manufacturer shall provide proof that the wind turbine has been erected properly and, as far as necessary, tested to ensure that operation is safe. In the absence of such proof, appropriate tests shall be carried out when putting the installation into operation. The commissioning is performed under surveillance of GL.

(3) This surveillance covers witnessing by the inspector of at least 10 % of the wind turbines during the actual commissioning, whereas GL is obligated to follow up failures/deficits. In case the requirements are not met, the amount of surveillance will be increased accordingly. The other turbines will be inspected after commissioning and the relevant records will be scrutinized.

(4) In the course of commissioning, all the functions of the wind turbine derived from its operating mode shall be tested. This includes the following tests and activities:

- functioning of the emergency stop button
- triggering of the brakes by every operating condition possible in operation
- functioning of the yaw system
- behaviour at loss of load (grid loss)
- behaviour at overspeed
- functioning of automatic operation
- visual inspection of the entire installation
- checking the logic of the control system's indicators

(5) In addition to the tests, the following items shall be examined during commissioning surveillance by visual inspection of the entire wind turbine (see Section 9.2):

- general appearance
- corrosion protection
- damages

- conformity of the main components with the certified design and traceability / numeration of the components

1.2.3.8 Final Assessment

Prior to the issue of the Project Certificate, all parts of the certification (Certification Reports, Inspection Reports, Statements of Compliance, Type Certificate) will be checked for consistency and completeness with regard to the elements and modules described in this Guideline.

1.2.3.9 Periodic Monitoring

(1) To maintain the validity of the certificate, maintenance of the wind turbine shall be carried out in accordance with the approved maintenance manual, and the condition of the installation shall be monitored periodically by GL in accordance with Chapter 11 “Periodic Monitoring”. Maintenance shall be carried out and documented by an authorized person accepted by GL. The Periodic Monitoring interval is four years as a rule. This interval may be varied depending on the condition of the installation.

(2) Any damage or major repairs shall be reported to GL. To maintain validity of the certificate, any alterations have to be approved by GL. The extent to which this work is supervised shall be agreed with GL.

(3) The maintenance records will be perused by GL. The Periodic Monitoring by GL comprises the following assemblies:

- foundation
- tower
- nacelle
- all parts of the drive train
- hydraulic/pneumatic system
- safety and control systems
- electrical installations
- rotor blades

(4) Details on the Periodic Monitoring are given in Chapter 11.

1.3 Basic Principles for Design and Construction

1.3.1 General

(1) The basis for this Guideline is provided by the general principles of reliability and durability of structures, as contained for example in ISO 2394 "General principles on reliability for structures" or DIN EN 1990 "Eurocode: Basis of structural design".

(2) Wind turbines intended to be certified shall be so designed, manufactured and maintained as to guarantee safe and economic operation during their envisaged operating life. This in particular requires proof that

- the installation is capable of withstanding all loads (see Section 1.3.2.1) assumed to occur during manufacture and the envisaged operating life (ultimate limit states), and that
- the installation remains operable under the influence of each of the loads to be assumed in this connection (serviceability limit states).

(3) The wind turbine should normally be so designed that minor causes cannot result in disproportionately heavy damage. This can for instance be achieved by

- designing the important components so that failure of a part does not result in destruction of the entire installation, or
- ensuring that all important components are capable of withstanding all foreseeable influences.

(4) Inspection and maintenance intervals shall be planned to provide adequate assurance that no significant deterioration in the condition of the plant can arise in the interval. The design shall take into account the practicability of carrying out inspections of relevant components.

(5) Where inspection is not practicable, the component shall be so designed and made that adequate durability for the entire operating life of the installation is assured.

1.3.2 Definitions

1.3.2.1 Loads

Loads in the sense of this definition are all actions and interactions with the environment which cause a loading of the structure.

1.3.2.2 Limit states

The integrity of a structure or its components shall be proved by the investigation of limit states. The limit states are divided into two groups, the ultimate limit states and the serviceability limit states, which in turn may be subdivided further.

1.3.2.2.1 Ultimate limit state

(1) The ultimate limit state, which generally corresponds to the maximum load-bearing capacity, includes for example the following states:

(2) Rupture of critical parts of a structure comprising components, cross-sections and connections, for instance by:

- fracture / exceedance of ultimate strength
- loss of stability (buckling)
- fatigue

(3) Loss of the static equilibrium of a structure or its parts (e.g. overturning as a rigid body).

1.3.2.2.2 Serviceability limit state

Depending on design and function, the serviceability limit state is determined by various limiting values which are oriented towards the normally envisaged use of the wind turbine. Limits to be observed are, amongst others:

- deformations
- vibration amplitudes and accelerations
- crack widths
- stresses and strains

1.3.2.3 Partial safety factors for loads

(1) The partial safety factors for the loads γ_F shall effect that, taking into account the probability of the load occurring, certain limiting values will not be exceeded with a given probability. These partial safety factors reflect the uncertainty of the loads and their probability of occurrence (e.g. normal and extreme loads), possible deviation of the loads from the representative/characteristic values, plus the accuracy of the load model (e.g. gravitational or aerodynamic forces).

(2) The partial safety factors for the loads are independent of the materials used and are stated for all load components in Section 4.3.5.

(3) To ensure reliable design values, the uncertainties and variances of the loads are covered by the partial safety factors for the loads as defined in equation 1.3.1.

$$F_d = \gamma_F F_k \qquad (1.3.1)$$

where:

F_d design values of the loads

γ_F partial safety factors for the loads

F_k characteristic values of the loads. In this Guideline, the alternative term "representative value" is used in cases for which the characteristic value cannot easily be determined by statistical means.

(4) The partial safety factors used according to this Guideline for the loads shall consider:

- the possibility of unfavourable deviations of the loads from characteristic values
- uncertainties in the load model

(5) These varying uncertainties are in some cases considered by means of individual partial safety factors. In this Guideline, as in most other codes, the load-related factors are grouped together in a partial safety factor γ_F.

1.3.2.4 Partial safety factors for materials

(1) The partial safety factors for materials γ_M take into account the dependence on the type of material, the processing, component geometry and, if applicable, the influence of the manufacturing process on the strength.

(2) The design resistances R_d to be used for the strength analyses are derived by division of the characteristic strength R_k by the partial safety factor for materials as per equation 1.3.2.

$$R_d = R_k/\gamma_M \qquad (1.3.2)$$

(3) The partial safety factors for materials are stated, in dependence on the materials, in Sections 5.3, 5.4 and 5.5.

1.3.3 Analysis procedure

(1) The stress S in a component is in this case determined using the design loads applicable for the respective limit state.

$$S = S(F_d) \qquad (1.3.3)$$

(2) General proof is then required that the stresses resulting from the design loads remain below the design strengths.

$$S \leq R_d \qquad (1.3.4)$$

(3) The partial safety factor procedure aspired to in ISO 2394 "General principles on reliability for structures" and DIN EN 1990 "Eurocode: Basis of structural design" cannot always be applied directly to wind turbines, because the operating state of the wind turbine in interaction with the environment results from the equilibrium of various load components. In such cases, the determination of section loads and stresses shall be carried out using the characteristic loads. The individual influences affected by uncertainty (e.g. rotational speed, aerodynamic forces) shall then be systematically varied so as to maintain the safety level implicitly defined by the partial safety factors. As a simplification, the section forces and stresses calculated on the basis of characteristic loads may be multiplied by the partial safety factor for loads most unfavourable for the particular load combination.

1.3.4 Mathematical model

(1) Stresses are usually determined by means of mathematical models, in which the behaviour of the wind turbine or its components, and the types of loads acting on it, are idealized and approximated.

(2) The model and type of approximation chosen shall be appropriate for the limit state to be investigated.

(3) Dimensioning is possible on the basis of test results. However, these must be statistically well-founded.

Note:

In supplement to the global analysis of the load-carrying system, it may be necessary to investigate stresses occurring locally (e.g. in zones of concentrated loads).

Appendix 1.A National Requirements in Germany

1.A.1 General

(1) The approval of wind turbines concerning structural integrity within Germany is carried out according to the “Bauordnungsrecht” (Building Regulations Law) as detailed below in Sections 1.A.1.1 to 1.A.1.4. Therefore, all relevant building codes shall be observed, especially with respect to the requirements for material / shop approvals and analyses. Beside the procedures in the “allgemeine bauaufsichtliche Zulassung” (general building permission issued by DIBt Deutsches Institut für Bautechnik, Berlin), the following standards and regulations, among others, shall be observed:

(2) The approval of wind turbines concerning grid code compliance within Germany is based on the legal and other documents listed or referenced in Section 1.A.1.5. In order to receive any energy payment according to the German Energy Feed-in Act (EEG), it is required for each wind farm built in Germany after June 30th 2010 to fulfil the legal requirements (see 1.A.1.5), e.g. by having a valid Project Certificate (GCC) for Grid Code Compliance (“Anlagenzertifikat”). Such a Project Certificate (GCC) is based on a Type Certificate (GCC) on wind turbine level (“Einheitenzertifikat”), which is required by law.

1.A.1.1 Material requirements

DIN EN 10204	Metallic products – Types of inspection documents
DIN 1045-2	Concrete, reinforced and prestressed concrete structures – Part 2: Concrete; Specification, properties, production and conformity
DIN EN 206-1	Concrete – Part 1: Specification, performance, production and conformity
DIN EN 12843	Precast concrete products – Masts and poles
DIN 18 800-1	Structural steelwork – Part 1: Design and construction
DIN 18 800-7	Steel structures – Part 7: Execution and constructor’s qualification

1.A.1.2 Requirements for manufacturers

DIN 1045-3	Concrete, reinforced and prestressed concrete structures – Part 3: Execution of structures
DIN 18 800-7	Steel structures – Part 7: Execution and constructor’s qualification

1.A.1.3 Analysis

(1) “Richtlinie für Windenergieanlagen; Einwirkungen und Standsicherheitsnachweise für Turm und Gründung” [Regulation for Wind Energy Conversion Systems; Actions and Verification of Structural Integrity for Tower and Foundation], DIBt Deutsches Institut für Bautechnik (German Institute for Civil Engineering), 2004, [4.2], and the standards mentioned therein.

(2) The DIBt Regulation applies to the analyses of the structural integrity of towers and foundations of wind turbines, and contains provisions concerning the effects on the entire wind turbine (load assumptions), based on DIN EN 61400-1.

(3) The DIBt Regulation was taken into account for the compilation of this Guideline. The relevant requirements for the analyses of tower and foundation have been harmonized with the DIBt Regulation.

(4) The load assumptions described in this Guideline cover the requirements for the load and safety level of the DIBt Regulation. The DIBt Regulation refers to DIN EN 61400-1:2004, not to DIN EN 61400-1:2006 [4.7]. This means that DIN EN 61400-1:2006 must not be applied for type approvals according to the DIBt Regulation, according to [4.3]. Additionally, the varying wind conditions of the DIBt Regulation (see Section 1.A.3), and the load case DLC 6.1 of the DIBt Regulation with a partial safety factor for wind loads on tower and foundation of $\gamma_F = 1.5$ without oblique inflow shall be considered.

1.A.1.4 Guidelines for measurements

“Technische Richtlinien” [Technical Guidelines], published by Fördergesellschaft Windenergie und andere Erneuerbare Energien e.V. (FGW), with the following parts:

– **Part 1** Determining the Noise Emission Values

- **Part 2** Determining the Power Performance and Standardised Energy Yields
- **Part 3** Determination of electrical characteristics of power generating units connected to MV, HV and EHV grids
- **Part 4** Demands on Modelling and Validating Simulation Models of the Electrical Characteristics of Power Generating Units and Systems
- **Part 5** Determining and applying the Reference Yield
- **Part 6** Determination of the Wind Potential and Energy Yields
- **Part 8** Certification of the Electrical Characteristics of Power Generating Units and Systems in the Medium-, High- and Highest-voltage Grids

1.A.1.5 Grid Code Compliance

(1) Wind turbines to be erected in Germany after June 30th 2010 need to be tested according to Section 1.A.1.4 Part 3.

(2) Wind turbines to be erected in Germany after June 30th 2010 need to be certified according to Section 1.A.1.4 Part 8.

(3) Wind farms to be connected in Germany after June 30th 2010 need to be in compliance with Section 1.A.1.5, para 4. This can be shown by a corresponding Project Certificate (GCC).

(4) The German law requires grid code compliance based on the Ordinance on System Services by Wind Energy Plants – System Service Ordinance ("Verordnung zu Systemdienstleistungen durch Windenergieanlagen – Systemdienstleistungsverordnung – SDLWindV), dated July 3rd, 2009, issued in the Federal Law Gazette "Bundesgesetzblatt Jahrgang 2009 Teil I Nr. 39, ausgegeben zu Bonn am 10. Juli 2009", page 1734.

(5) German Grid Codes are named in Section 1.A.1.5, para 4; their requirements are described in more detail for some points.

Note:

Additional requirements can arise from other local German Grid Codes. A regularly updated list of international grid codes can be found at the following web page: http://www.gl-group.com/pdf/IGCC_list.pdf

1.A.2 Analysis concept

1.A.2.1 Wind conditions

(1) The wind conditions to be considered for wind turbines in the Federal Republic of Germany are given in the DIBt Regulation and the associated Appendix B – Wind loads. The first sentence of Annex B within the DIBt Regulation shall be neglected; Annex B remains valid, according to [4.3]. The already issued DIN 1055-4:2005 must not be applied.

(2) However, in order to cover possible changes in the validity of Annex B in the future, it has been recommended by Germanischer Lloyd that the requirements of DIN 1055-4:2005 be included for the dimensioning of wind turbines for German type approvals.

1.A.2.2 Towers

(1) The analysis of steel towers shall be carried out according to ENV 1993 (Eurocode 3) or DIN 18800, DIN 4131 and DIN 4133.

(2) For concrete towers, the relevant parts of DIN 1045-1 or DIN 4228 shall be used.

1.A.2.3 Foundations

DIN 1054 (global safety factors) is valid in Germany for foundations and the permissible soil pressure.

Appendix 1.B National Requirements in Denmark

1.B.1 General

(1) In Denmark the type approval of wind turbines (“Typegodkendelse af Vindmøller”) is carried out by bodies who are accredited and whose accreditation is acknowledged by the Danish Energy Agency (“Energistyrelsen”). The procedures for the certification are laid down in the Executive Order by the Danish Energy Agency (“Energistyrelsen”) No. 651 dated 26 June 2008: “Bekendtgørelse om teknisk godkendelsesordning for konstruktion, fremstilling, opstilling, vedligeholdelse og service af vindmøller” (“Executive order on the technical certification scheme for design, manufacture, installation, maintenance and service of wind turbines“) (DEO) and the associated “Energistyrelsens vejledning om teknisk godkendelsesordning for konstruktion, fremstilling og opstilling af vindmøller i Danmark” (“The Danish Energy Agency’s guidelines for the technical certification scheme for the design, manufacture and installation of wind turbines in Denmark”) (DEA Guideline).

(2) The technical principles for the requirements are given in IEC WT01 “IEC System for Conformity Testing and Certification of Wind Turbines Rules and Procedures”. The DEO explains how to use the IEC WT01, whereas the DEA Guideline explains certain details. The manufacturers of the wind turbines as well as, in principle, the maintenance suppliers are required to operate a quality system which has been certified according to ISO 9001 by an accredited certification body.

(3) The accreditations of GL for the certification of wind turbines and for the certification of quality systems have been acknowledged by the Danish Energy Agency.

1.B.2 Regulations and standards

(1) The Executive Order No. 651 (DEO) covers the following areas:

- type certification
- project certification
- certification for testing and demonstration
- certification of modifications, relocation and use after the expiry of a certificate for testing and demonstration
- type certification of wind turbines with a rotor area of 5 square metres or less
- grid connection
- maintenance, service and major damage
- certifying bodies
- administrative provisions, inspection, monitoring etc.

(2) For design and dimensioning, the DEO references other standards (mainly of the IEC).

(3) The DEA Guideline for the technical certification scheme provides additional information on each section of the DEO.

(4) These regulations and standards apply to wind turbines which are installed onshore and offshore (in territorial waters and the exclusive economic zone) and which are used for electricity production.

(5) The currently valid list of applicable rules and recommendations is available on the Internet under “http://www.wt-certification.dk/UK/Rules.htm”. The list of Registered bodies can be found under “http://www.wt-certification.dk/UK/Bodies.htm”.

Appendix 1.C National Requirements in the Netherlands

1.C.1 General

(1) In order to obtain building permission in the Netherlands, it is necessary to have a Type Certificate (“type certificaat”). Certification bodies accredited by Raad voor de Accreditatie (RvA) are allowed to carry out the Type Certification.

(2) The accreditations of GL for the certification of wind turbines and for the certification of quality systems have been acknowledged by RvA.

(3) On 27 March 2006, it was formally declared by the Netherlands Electro-technical Committee (NEC) 88 that the combination of IEC 61400-1, Edition 3 and IEC WT 01 became the successor of the Netherlands prestandard NVN 11400-0, 1999.

1.C.2 Scope

(1) The criteria defined by NEC 88 apply to wind turbines producing electricity that are connected to the electrical power network.

(2) These criteria apply to a wind turbine, including the tower and the connection between the tower and the foundation, but do not include the foundation itself. The criteria, however, also cover the requirements to be imposed on the foundation insofar as these arise from the design of the wind turbine.

(3) In the Netherlands, the European standards, IEC standards, ISO standards and Netherlands NEN standards apply.

1.C.3 Certification requirements

(1) According to the criteria given by NEC 88, compliance with the requirements of IEC 61400-1, Edition 3, shall be demonstrated by means of Type Certification.

(2) In the Netherlands, Type Certification shall follow the procedures as specified in IEC WT 01. The certification can be limited to all mandatory modules. It may be extended to include one or more of the optional modules.

Appendix 1.D National Requirements in Canada

1.D.1 General

The following information was taken from the Canadian guide “CSA Guide to Canadian wind turbine codes and standards – Draft version 1.2 – January 2008” (www.csa.ca). Further details are given there.

1.D.2 Section A – Introduction and general information

(1) Section A gives a general introduction, describes the scope of the document, and provides background information on the situation in Canada as well as on available and applicable standards.

(2) The CSA guide provides general information on codes and standards regarding the approval, design, installation, operation and maintenance of wind turbines for use in Canada.

1.D.3 Section B – Specific regulatory and approval subject areas

Section B includes specific information on zoning, public hearings, power purchase agreements, building permits, electrical plan approval/permitting, site suitability, evaluation of impact on water, air, and wildlife, acoustic noise, electrical connections (off-grid and grid-connected) as well as technical information on foundations, towers, markings, electrical safety, environmental design considerations / external conditions, load cases, lightning protection, rotor blades, mechanical systems, performance measurement, power quality and worker safety.

Appendix 1.E National Requirements in India

1.E.1 General

(1) The approval of wind turbines in India is carried out by the Centre for Wind Energy Technology (C-WET) on the basis of the "TAPS-2000, Type Approval – Provisional Scheme, Provisional Type Certification Scheme for Wind Turbine Generator Systems in India, amended in April 2003" issued by the Ministry of Non-conventional Energy Sources, New Delhi, India.

(2) TAPS-2000 contains fundamental rules, procedures, requirements and technical criteria for the certification of wind turbines in India. It shall only be used for horizontal-axis plants that have a swept rotor area of more than 40 m^2 and are operated in a network.

(3) In general, the technical assessment of the wind turbine is based on IEC 61400-22, IEC 61400-1 and the Indian design requirements as per TAPS-2000, Annexure 2.

1.E.2 Certification categories

A wind turbine can be certified according to the following three categories:

1.E.2.1 Category I

(1) The wind turbine types that possess a valid type certificate or approval from an accredited Certification Body fall under this category. If minor changes/modifications are introduced in the design, the certification can be performed as per this category. The following certifications are recognized:

- Type Certificate as per Germanischer Lloyd
- Type Certificate as per IEC WT01 and IEC 61400-22
- Danish Type Certificate as per Danish Energy Agency, Approval Classes A and B
- Netherlands Type Certification scheme

(2) The following modules shall be considered compulsory:

- Partial Design Evaluation / Review of Valid Type Certificate
- Manufacturing System Evaluation
- Review of Foundation Design Requirements

1.E.2.2 Category II

Wind turbines with a valid Type Certificate for operation under Indian conditions fall under this category. The modules as for category I, but with an enlarged scope of design verification, are compulsory. Additionally, tests and measurements shall be performed at wind turbines.

1.E.2.3 Category III

(1) New or significantly modified wind turbines that do not possess a valid Type Certificate fall under this category.

(2) The following modules are to be considered compulsory:

- Design Evaluation
- Manufacturing System Evaluation
- Provisional Type Testing

1.E.3. External conditions for India (corresponding to TAPS-2000, Annexure 2)

The external conditions for India are given in Annexure 2. An outline of these conditions is listed below:

- For wind conditions, the following requirements shall apply:
    - normal operating wind conditions (Weibull parameters and turbulence intensity) according to IEC 61400-1
    - extreme wind speed conditions with reference to Indian Standard IS 875 (Part 3) – 1987
- Ice formation shall not be considered.
- Extreme design temperature range will be in the interval from -5 °C to +60 °C, with the normal operating temperature range +0 °C to +50 °C.
- Humidity up to 99 % shall be considered.
- Design air density shall be considered to be at least 1.20 kg/m^3.
- Electrical grid outages shall be assumed to occur 350 times per year. The maximum outage duration for which the wind turbine shall be designed is at least one week.

Appendix 1.F National Requirements in China

1.F.1 General

(1) The approval of wind turbines within China by a third party or accredited certification body is not mandatory yet. However, due to the ongoing development of the wind energy industry in China, the responsible ministry is in hearing with the aim of promulgating the relevant rules in a statutory form.

(2) At present, the competent Chinese authority – the Standardization Administration of the People's Republic of China (SAC) – assigns the standard SAC TC50 in correspondence with IEC TC88 in harmonizing the relevant technical standards for the wind energy industry.

(3) The accreditations of GL for the certification of wind turbines and for the certification of quality systems are recognized in China.

1.F.2 Status of standardization work

(1) For some aspects there is no standard, and some of the existing national standards are based on earlier versions of IEC standards, which need to be updated. In addition, there is a lack of adequate observation data, analysis and research in the aspect of wind resources and wind conditions (wind model).

(2) Therefore, wind power-related standards have been drafted and revised in the past few years, mainly including IEC WT01:2001 combined with specific conditions, resulting in the "Rules and Procedures for Conformity Testing and Certification of Wind Turbines".

(3) With reference to IEC 61400-1:2005, the existing national standard GB 18451.1:2001 will be revised.

(4) In respect of further IEC standards, the other wind turbine-related national standards (including blade, tower, gearboxes, generators etc.) as well as wind turbine testing standards will be revised.

(5) In addition, under the support of the Chinese government, the installation of hundreds of meteorological masts in those regions with good wind resources has commenced, in order to carry out wind resource observations. The resulting data will be used to develop research on Chinese wind conditions (wind model).

1.F.3 Regulations and standards

(1) GB (Guo Biao) – Chinese national standards, which include the following rules for the wind energy industry. In the following list, T (Tuijian) means recommendation, indicating that these standards are recommended for application:

GB 18451.1-2001
Wind turbine generator systems – Safety requirements (identical to IEC 61400-1:1999)

GB/T 18451.2-2003
Wind turbine generator systems – Power performance test (identical to IEC 61400-12:1998)

GB/T 18709-2002
Methodology of wind energy resource measurement for wind farms

GB/T 18710-2002
Methodology of wind energy resource assessment for wind farms

GB/T 19069-2003
Controller of wind turbines generating system – Technical condition

GB/T 19070-2003
Controller of wind turbine generator systems – Test method

GB/T 19071.1-2003
Asynchronous generator of wind turbine generator systems
Part 1: Technical condition

GB/T 19071.2-2003
Asynchronous generator of wind turbine generator systems
Part 2: Test method

GB/T 19072-2003
Tower of wind turbine generator systems
GB/T 19073-2008
Gearbox of wind turbines generating system

GB/T 19568-2004
Assembling and installation regulation for wind turbine generator systems

GB/T 19960.1-2005
Wind turbine generator systems
Part 1: General technical specification

GB/T 19960.2-2005

Wind turbine generator systems

Part 2: General test method

GB/T 20319-2006

Code for the acceptance of wind turbine generator systems

GB/T 20320-2006

Measurement and assessment of the power quality characteristics of wind turbine generator systems (identical to IEC61400-21:2001)

(2) JB (Jiexie Biaozhun) – mechanical industry standard, which falls within the category of ministry-level standards; JB standards include the following rules for the wind energy industry. In the following list, T (Tuijian) means recommendation, indicating that these standards are recommended for application:

JB/T 7323-1994

Test methods for wind turbines

JB/T 10194-2000

Rotor blades – wind turbine generator system

JB/T 10300-2001

Wind turbine generator system – design requirements

JB/T 10425.1-2004

Yaw system of wind turbine generator systems

Part 1: Technical condition

JB/T 10425.2-2004

Yaw system of wind turbine generator systems Part 2: Test method

JB/T 10426.1-2004

Braking system of wind turbine generator systems

Part 1: Technical condition

B/T 10426.2-2004
Braking system of wind turbine generator systems
Part 2: Test method

JB/T 10427-2004
General hydraulic system of wind turbine generator systems

JB/T 10705-2007
Rolling bearings – wind turbine generator bearings

(3) DL (Dian Li) – electrical industry standard, which falls within the category of ministry-level standards; DL standards include the following rules for the wind energy industry. In the following list, T (Tuijian) means recommendation, indicating that these standards are recommended for application:

DL/T 666-1999
Code on the operation of wind power plants

DL 796-2001
Code on the safety of wind farms

DL/T 797-2001
Code on the maintenance of wind farms

DL/T 5067-1996
Code on the compiling of feasibility study reports for wind power projects

DL/T 5191-2004
Code on the construction acceptance of wind power plant projects

(4) CEPRI (China Electrical Power Research Institute) has issued electrical grid rules:

GB/Z 19963-2005
Code on grid technology for wind farms

(5) Further details are given at:
http://www.sac.gov.cn/templet/default/displayTechnicalCommitteeInfo.do?tcId=906

Appendix 1.G National Requirements in Japan

1.G.1 General

(1) The approval of wind turbines within Japan by a third party or accredited certification body is not mandatory yet. However, there are two major laws that wind turbines are required to satisfy: the Electric Utility Law and the Building Standard Law.

(2) The accreditations of GL for the certification of wind turbines and for the certification of quality systems are recognized in Japan.

1.G.2 Regulations and standards

There are two major laws regarding the safety requirements of wind turbines. The potential wind turbine owner (the applicant) must obtain approvals from the Ministries.

1.G.2.1 The Electric Utility Law (Denki Jigyou Hou)

(1) The applicant must submit a Notice of Construction Plan to the regional office of the Nuclear and Industrial Safety Agency, which is a part of the "Ministry of Economics, Trade and Industry", before starting the construction of wind turbines.

(2) The application should be accompanied by the design documentation, including the safety evaluation of the structure. This is true even if the proposed wind turbines have type certificates from an accredited certification body.

1.G.2.2 The Building Standard Law (Kenchiku Kijun Hou)

(1) This law mandates that an approval (a building permit) must be obtained from the "Ministry of Land, Infrastructure, Transportation and Tourism" for any structure taller than 60 m above ground level.

(2) In case of a wind turbine, the support structure including the tower and foundation are subject to this law. Although the rotor nacelle assembly is out of the scope of this law, the height of a wind turbine is determined as being the highest point of a rotor plane, not the hub height.

(3) To apply for the Ministry's approval, the applicant must first apply for performance evaluation at a designated performance evaluation agency in the private sector.

(4) The application documents must be prepared in accordance with the regulations associated with the Building Standard Law. These regulations are unique to the Japanese market, and they are not compatible with the international standards such as ISO and IEC.

(5) It should be noted that this evaluation process could take several months. After the performance evaluation is completed, the applicant can then file an application for the Ministry's approval. This legal procedure is same as that applied to skyscraper buildings, including the dynamic simulation of the wind turbine structure for major earthquakes.

(6) The law mandates that the materials used for buildings and general structures including wind turbines must conform to the Japanese Industrial Standards (JIS) or Japanese Agricultural Standards (JAS, applied to wooden structures). The materials and components not certified for JIS/JAS have to be tested to prove their conformity with the Japanese standards.

1.G.2.3 Wind Power Guideline for Japan (NEDO Guideline)

(1) This guideline provides the typical procedures for estimating the extreme wind speeds, turbulence intensity and the lightning intensity at the proposed wind farm site in Japan. The guideline was published in 2008 after a three-year research project funded by the NEDO (New Energy and Industrial Technology Development Organization), which is a governmental organization under the Ministry of Economy, Trade and Industry (METI). NEDO is preparing the English version of the guideline.

(2) This guideline is intended to help the wind turbine owners by providing easier evaluation of the environmental conditions at the site. Its use is not mandatory; the owner may choose to employ other technical approaches in evaluating the environmental conditions.

Appendix 1.H Certification of Small Wind Turbines

1.H.1 General

(1) Small Wind Turbines (SWT) are defined as per IEC 61400-2.

(2) The requirements for SWT are listed in IEC 61400-2. If any requirement is not defined in sufficient detail by IEC 61400-2 the requirements listed in the present Guideline should be taken into consideration as complementary, if applicable.

(3) The different certification procedures as described in section 1.2 “Extent of Certification” are transferable and applicable for the certification of small wind turbines in accordance to this guideline.

(4) Certification of a small wind turbine on the basis of this Guideline is carried out by Germanischer Lloyd Industrial Services GmbH, Renewables Certification (GL) with regard to the items specified in Section 1.2.

(5) The extent of certification for small wind turbines is analogous to the ones for larger wind turbines (cf. Section 1.2).

(6) In reference to the verifications of SWT according to IEC 61400-2, further helpful information can be found in the different Sections of the present GL Guideline.

1.H.2 National and international requirements

(1) The German Type Approval has to be performed according to the DIBt regulation. The current edition 2004 limits the applicability of SWT to 40m². Additionally further requirements shall be considered. In comparison to the IEC 61400-2 two independent braking systems are required. The consideration of icing could be relevant, too. Further SWT configuration specific requirements might be relevant.

(2) For implementation of a SWT in the Danish market it is necessary to carry out a Type Certification according to Danish Executive Order (DEO) Act no. 651 of 26 June 2008.

(3) For implementation of a SWT in the British market it is necessary to carry out a certification according to the Microgeneration Certification Scheme (MCS), Edition 2008 and BWEA standard "Small Wind Turbine Performance and Safety Standard" dated 29 February 2008.

1.H.3 Requirements for load assumptions

(1) The applicability of the simplified load calculation method listed in Chapter 5.2 and 7.4 of the current IEC 61400-2, Ed. 2 has to be checked for the specific SWT configuration (e.g. high yawing rates, especially for free yaw systems).

(2) The turbulence intensity might be increased properly due to occurrence on specific areas of installation (e.g. urban areas).

1.H.4 Requirements for rotor blades

(1) This requirement refers to section 7.8.1, item d. of the current IEC 61400-2, Ed. 2. In reference to this the environmental effects (e.g. corrosion, UV degradation, humidity, temperature etc.) shall be considered.

(2) The environmental effects on fibre reinforced plastic materials (e.g. material degradation/aging due to UV radiation, humidity, embrittlement etc.) of the rotor blades shall be considered by a material degradation factor of 1.35. This factor can be reduced if representative tests show lower degradation effects.

(3) The pure strength reduction of fibre reinforced plastics due to material temperatures higher than room temperature shall be considered by a material degradation factor of 1.1. This factor can be set to 1.0 if the coupon tests are executed at the highest temperature the wind turbine will be installed.

(4) The environmental effect corrosion shall be excluded by adequate means of corrosion protection over the lifetime of the wind turbine.

(5) The above mentioned factors derive Section 5.5.2.4. These factors refer only to the above mentioned item d of Section 7.8.1 of IEC 61400-2. Further partial safety factors need to be considered, too (see Section 7.8 of IEC 61400-2).

(6) In reference to table 6 listed in Section 7.8.1 of the current IEC 61400-2, Ed. 2 it is recommended to distinguish between different partial safety factors in dependence of the chosen material (e.g. concrete, FRP, metallic).

(7) The Appendix E.4.2 of the current IEC 61400-2, Ed. 2 lists further safety factors as an orientation, too.

1.H.5 Requirements for electrical installations

(1) Generally the SWT shall be protected against over voltages (e.g. atmospheric or switching) by surge protective devices (SPD). In case of limited space within a SWT such kind of equipment might be installed in separate cabinets outside of the SWT. The cabinets shall be suitable for the environmental conditions.

(2) Due to the requirements for lightening protection given in the IEC 61400-2 a SWT shall have its own earthing electrode system. It might be necessary to adapt the design to local network conditions (e.g. TN-C-S, TT).

(3) As an option backup battery systems can be assessed in addition to the requirements listed in IEC 61400-2 acc. to Chapter 8.1 "Charging Equipment and Storage Batteries".

1.H.6 Requirements for testing

(1) Functionality tests of single components or systems can be performed on test benches, too. These tests shall be performed by a ISO/IEC 17025 accredited institute or witnessed by GL.

(2) The complete small wind turbine system will be checked during the witnessing of commissioning. The commissioning of one of the first turbines shall be witnessed by GL (cf. Section 10.8).

Appendix 1.I IEC- and CENELEC Standards

1.I.1 General

(1) The international standards for wind turbines have been compiled since 1988 by Technical Committee 88 of the International Electrotechnical Commission. TC 88 has a number of working groups, project teams and maintenance teams which have produced or are revising the standards, technical reports (TR) and technical specifications (TS).

(2) Each document produced by the IEC is distributed within the European Committee for Electrotechnical Standardization (CENELEC) for parallel voting. Documents which thereby attain the status of a European standard are also published as a German standard (DIN, VDE).

(3) In addition to the standards taken over by IEC, TC 88 of the CENELEC also has own EN standards compiled by several European working groups. The documents listed in the following section are listed by title, and without the dates of issue and revision.

(4) Dates of issue are added in parenthesis only in those cases where two editions of standards are in current use.

1.I.2 List of normative documents in the area of wind energy

IEC 60034	Rotating Electrical Machines
IEC 60050-415	International Electrotechnical Vocabulary - Part 415: Wind turbine generator systems
IEC 61400-1	Safety Requirements (1999)
IEC 61400-1	Design Requirements (2005)
IEC 61400-1/A1	Amendment to IEC 61400-1
IEC 61400-2	Design Requirements for Small Wind Turbines
IEC 61400-3	Design Requirements for Offshore Wind Turbines
IEC 61400-11	Acoustic Noise Measurement Techniques
IEC 61400-12-1	Power Performance Measurements of Electricity Producing Wind Turbines
IEC TS 61400-13	Measurement of Mechanical Loads
IEC TS 61400-14	Declaration of Apparent Sound Power Level and Tonality Values
IEC 61400-21	Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines (2001)
IEC 61400-21	Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines (2008)
IEC TS 61400-23	Full-Scale Structural Testing of Rotor Blades
IEC 61400-24	Lightning Protection
IEC 61400-25	Communication Standard for Control and Monitoring of Wind Power Plants (Part 1-5)
DIN EN 61400-1	Design requirements
DIN EN 61400-2	Design requirements for small wind turbines
DIN EN 61400-11	Acoustic noise measurement techniques
DIN EN 61400-12-1	Power Performance Measurements of Electricity Producing Wind Turbines
DIN EN 61400-21	Measurement and assessment of power quality characteristics of grid connected wind turbines
DIN IEC 61400-24	Lightning Protection
DIN EN 61400-25	Communication Standard for Control and Monitoring of Wind Power Plants (Part 1-5)

DIN EN 50308	Wind turbines – Protective measures - Requirements for design, operation and maintenance
DIN EN 50308	Corrigendum to DIN EN 50308
pr EN 50373	Electromagnetic compatibility
DIN EN 50376	Declaration of sound power level and tonality values of wind turbines

1.I.3 Supply sources

IEC standards can be obtained via the web page “www.iec.ch”, EN standards via “www.cenelec.org” and DIN standards via “www.din.de”.

Rules and Guidelines
IV Industrial Services

1 Guideline for the Certification of Wind Turbines

2 Safety System, Protective and Monitoring Devices

Edition 2010

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Appendix 2.A

Appendix 2.B

Appendix 2.C

2.1 General

2.1.1 General

(1) The aim of this Chapter 2 “Safety System, Protective and Monitoring Devices” is to make sure that the prerequisites for the load assumptions as per Chapter 4 are safely met with respect to the operating conditions of the wind turbine. All possible conditions (e.g. rotational speed, pitch angles, …) of the wind turbine, including fault conditions not covered by protection functions, shall be considered in the load analysis.

(2) Meeting the requirements of Chapter 2 therefore contributes essentially towards ensuring that the wind turbine’s components are always kept within their limit states.

(3) Ensuring the occupational safety of personnel in or at the wind turbine is not the main focus of this chapter. However, fulfilment of the requirements of this chapter shall never influence occupational safety negatively.

Note:

For the aspects of occupational safety, please refer to the note after Section 1.1.1, para 6.

2.1.2 Assessment documents

(1) For the approval of the safety system and of the protective and monitoring devices, the following documents at least shall be submitted as a rule:

a) description of the wind turbine (type designation, general layout of the wind turbine, functional principles, ...)

b) description of the control concept and the control system (structure of the control system, sequences of starting and stopping procedures, behaviour of the wind turbine during normal operation, behaviour of the wind turbine on detection of malfunctions, ...)

c) statement of other parameters in the operation management (numerical values that have been set) that influence the loads of the wind turbine (cut-in and cut-out wind speeds, rotational speed values, power values, if applicable the control/regulation of the yaw movements, temperatures, ...)

d) description of the safety concept and the safety system (structure of the safety system, behaviour of the wind turbine following activation of the safety system, statement of the criteria for which the safety system is triggered, ...)

e) statement of all parameters set in the safety system (numerical values)

f) description of the sensors and, if applicable, measuring transducers of the safety system (type designation, setting values, time constants, ...)

g) description of the procedure for clearance of the wind turbine after activation of the safety system

h) description of the braking systems and their behaviour (structure of the braking systems, mode of operation, characteristic quantities, time constants, ...)

i) functional description of the locking devices as per Section 2.3.3

j) electrical and hydraulic (and, if applicable, also pneumatic) circuit diagrams at least to the extent that the function of the safety system is shown. In the circuit diagrams, the connection between the electrical and hydraulic (and, if applicable, also pneumatic) system shall be clearly recognizable. For hydraulic systems, please refer to Section 7.9, and for electrical diagrams to Section 8.1.

k) documentation of software used in the safety system (if applicable) as per Section 2.2.3.3, para 8

l) fault consideration as per Section 2.1.3

m) documentation of the required risk reduction through protection functions as per Section 2.1.4

(2) The documents shall show that the requirements set out in Chapter 2 are met. The degree of detail shall be so selected that the behaviour of the wind turbine is adequately defined with regard to the load assumptions.

(3) Appendix 2.B provides two tables that summarize the main parameters relevant to load assessment, as an expedient for data submission. The use of the tables is optional.

2.1.3 Fault consideration

(1) A consideration of possible faults and their effects

- in the safety system,
- in the braking systems,
- if a cut-out yaw error φ_A (see Section 2.2.2.11, para 2) was defined, in the yaw system
- if individual pitch operation is used to reduce the loads on the wind turbine, in all systems used for this function and
- if operational vibration or load monitoring is used as an input of the control functions in order to reduce the loads on the wind turbine, in all systems used for these functions

shall be submitted. In this consideration, all possible faults of these systems shall be specified.

(2) For each possible fault, the following information at least shall be given:

- designation and description of the possible fault
- affected component(s)
- possible cause(s)
- type of detection
- effect(s) of the fault
- measure(s) for limiting negative consequences

(3) The technique chosen for this examination (e.g. failure mode and effect analysis (FMEA), fault tree, ...) shall be selected as appropriate by the author of the documents.

Note 1:

In ISO 13849-1:2006, the technique mentioned for fault consideration is FMEA (IEC 60812).

Note 2:

Considerable faults for the control/safety system are listed in ISO 13849-2:2003 "Safety of machinery – Safety-related parts of control systems – Part 2: Validation".

(4) The fault consideration shall be used for the definition of load cases of the groups DLC 2.x (please refer to Section 4.3.3.2) and DLC 7.x (please refer to Section 4.3.3.7).

(5) The fault consideration shall also be used when showing that the required performance level is achieved (please refer to Section 2.1.4), e.g. for the evaluation of redundancies in the safety system and the evaluation of measures against possible dormant failures.

2.1.4 Required risk reduction through protection functions

(1) The protection functions (see Section 2.2.2.3) shall be listed. This list of protection functions should consist of all functions that are related to triggering of the safety system (e.g. turbine behaviour following overspeed), plus other functions designed for keeping the wind turbine inside the design conditions envelope (e.g. stopping the rotor blade rotation when reaching the feathering position).

(2) Each of the protection functions as listed per para 1 are to be related to a required performance level (PL_r). See Section 4.3 of ISO 13849-1:2006 "Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design".

Note 1:

A required performance level of $PL_r \geq d$ *is recommended for the protection functions.*

Note 2:

In Appendix 2.C, a list of protection functions is given to show an example and the possible format of such a list. The list given shall not be seen as a list of requirements.

(3) All components/systems (electric, electronic, hydraulic or other) of the control and safety system that take part in performing a protection function (see Section 2.2.2.3) shall be listed. They are considered "safety-related parts of a control system" (SRP/CS) as per section 3.1.1 of ISO 13849-1:2006.

(4) For the SRP/CSs listed according to para 3, it shall be shown that the performance level PL according to the PL_r derived as per para 2 is achieved. See section 4.5 of ISO 13849-1:2006.

(5) Documentation of the working steps as per para 1 to 4 shall be submitted to GL for plausibility checks. For documentation of the working steps as per para 3 to 4, the list in section 10 of ISO 13849-1:2006 can be followed.

2.2 Control and Safety System

2.2.1 General

The control and safety system shall optimize operation and keep the wind turbine in a safe condition in the event of a malfunction. The safety concept shall take into account the relevant operating values, such as admissible overspeed, decelerating moments, short-circuit moments, permissible vibrations etc. (see Section 2.2.3).

2.2.2 Definitions

2.2.2.1 Control concept and control system

(1) By control concept is meant a procedure aimed at operating the wind turbine efficiently, as free from malfunctions as possible, lightly stressed and safely. The logic of the procedure is generally incorporated into one or more programmed modules forming part of the overall control system.

(2) With the aid of the control system, the wind turbine shall be controlled, regulated and monitored according to the control concept. The control system shall keep the wind turbine within the normal operating limits.

2.2.2.2 Safety concept and safety system

(1) By safety concept is meant a part of the system concept intended to ensure that, in the event of a malfunction, the wind turbine remains in a safe condition. If malfunctions occur, it is the task of the safety system to ensure that the wind turbine behaves in accordance with the safety concept.

(2) The safety system is a system logically superordinate to the control system that is brought into action automatically after safety-relevant limiting values have been exceeded or if the control system is incapable of keeping the wind turbine within the normal operating limits. The safety system is intended to keep the wind turbine in a safe condition.

2.2.2.3 Protection functions

Protection functions are functions of the control system and/or safety system which ensure that the wind turbine remains within the design limits (for limit states, see Section 1.3.2.2). This is achieved by ensuring that the prerequisites for the load assumptions as per Chapter 4 are always met with respect to the wind turbine conditions (e.g. rotational speed, pitch angles, …; see Section 2.1.1, para 1).

Note:

The term “safety function” as used in ISO 13849-1:2006 covers the protection functions plus other possible functions providing safety for the maintenance personnel. For the aspects of occupational safety, please refer to the note after Section 1.1.1, para 6.

2.2.2.4 Braking system

(1) The braking system is a system which is capable of reducing the rotor rotational speed and keeping it below a maximum value or braking it completely to a standstill. A braking system includes all components which on demand contribute towards braking the rotor.

(2) A braking system may e.g. be of an aerodynamic or mechanical principle. It is driven electrically, hydraulically or by other means.

(3) In addition to the braking function, a braking system may be used for another purpose, e.g. controlling the power output or the rotational speed of the wind turbine.

2.2.2.5 Clearance

(1) Clearance is a human intervention in the sense of the execution of a necessary repair or elimination of the cause of a malfunction, followed by release of the wind turbine for operation. Clearance necessitates the presence and active involvement of a sufficiently qualified person on site at the wind turbine.

(2) Alternatively, sufficiently qualified personnel performing the clearance need not necessarily be on site at the turbine, but may perform the clearance from the remote control centre, if the following prerequisites (para 3 through 5) are met:

(3) The outside of the turbine shall be inspected from a distance before performing the clearance, to make sure that the main components are in place and appear to be undamaged. This inspection may be conducted e.g. from a neighbouring turbine. Use of monitoring cameras is allowed.

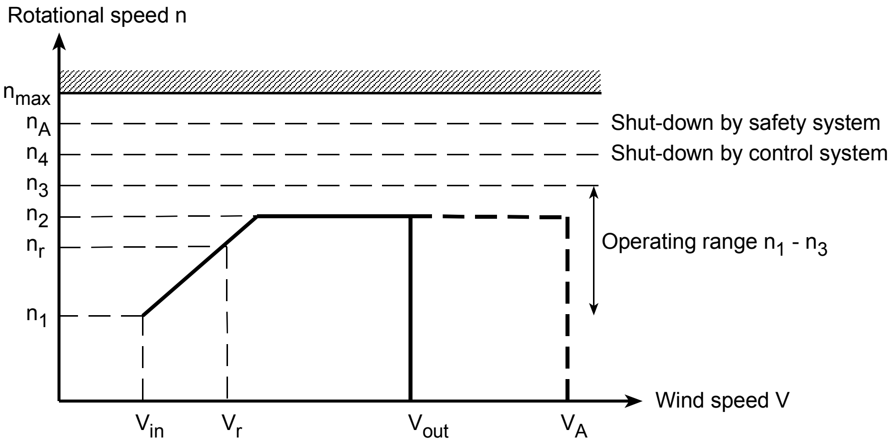

Fig. 2.2.1 Sketch of the rotational speed ranges, using the example of a variable-speed wind turbine

(4) The inside of the nacelle shall be inspected after the clearance and during the start-up procedure, to make sure that the main components are in place and undamaged. This inspection may be conducted by using monitoring camera(s) and microphones(s) or other suitable methods.

(5) The number of allowable remote clearances of the safety system shall be limited. For each possible failure, the documentation shall state

- the number of allowable remote clearances per 24 h period
- the number of allowable remote clearances as a total for the same failure

2.2.2.6 Rotational speed of the rotor

(1) The operating range comprises the rotational speed range of the rotor from the "minimum operating speed" n_1 to the "maximum operating speed" n_3, within which the rotational speed lies under normal operating conditions. The operating range may include ranges acceptable only for a short time (e.g. exclusion of resonance speeds).

(2) The "rated speed" n_r is the rotational speed at the rated wind speed V_r (see Section 2.2.2.8, para 2).

(3) The "set value of the speed controller" n_2 is used for variable-speed wind turbines in the operating state above the rated wind speed V_r (see Section 2.2.2.8, para 2). In this operating state, the rotational speed will deviate upwards or downwards from n_2 by a given tolerance.

(4) The "cut-out speed" n_4 is the rotational speed at which an immediate shut-down of the wind turbine must be effected by the control system.

(5) The "activation speed" n_A is the rotational speed at which immediate triggering of the safety system must occur.

(6) The "maximum overspeed" n_{max} may never be exceeded, not even briefly. For the speed rating requirements of the generator, see Section 8.2.2.

(7) When defining the rotational speeds, the interaction of the individual components, in particular the vibratory behaviour (e.g. natural frequencies) of the rotor blades, the drive train and the tower shall be taken into account.

2.2.2.7 Power

(1) The "rated power" P_r is the maximum continuous electrical power (active power) at the output terminals of the wind turbine (following a possible inverter system and before a possible transformer) resulting from the power curve under normal operating conditions. The power rating of the generator may differ from this value, as given in Section 8.2.2.

(2) The "over-power" P_T is the active electrical power at the output terminals of the wind turbine at which the control system must initiate a power reduction.

(3) The "activation power" P_A is the instantaneous active electrical power at the output terminals of the wind turbine at which immediate triggering of the safety system must occur.

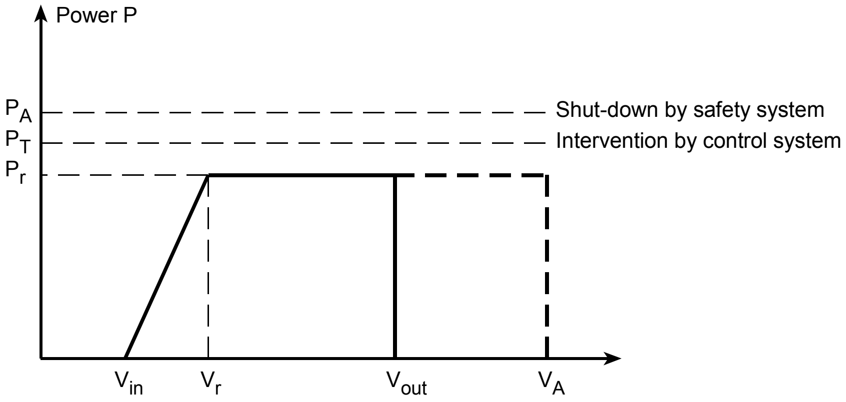

Fig. 2.2.2 Sketch of a power curve

2.2.2.8 Wind speed

(1) The "cut-in wind speed" V_{in} is the lowest mean wind speed at hub height (for the "normal wind profile model NWP", see Section 4.2.3.1.2) at which the wind turbine starts to produce power.

(2) The "rated wind speed" V_r is the lowest mean wind speed at hub height (for the "normal wind profile model NWP", see Section 4.2.3.1.2) at which the wind turbine produces the rated power according to Section 2.2.2.7, para 1).

(3) The "cut-out wind speed" V_{out} is defined as the maximum wind speed at hub height (averaging period to be defined by the manufacturer) at which the wind turbine must be shut down.

(4) The "short-term cut-out wind speed" V_A is the wind speed at hub height (averaging period typically 1 - 3 s, to be defined by the manufacturer) above which the wind turbine must be shut down immediately.

Note:

Normally, the wind speed stated in this Guideline is a 10 minute average wind speed.

2.2.2.9 Blade pitch angle

The blade pitch angle is the angle between the rotor plane and an airfoil chord. Wind turbines equipped with a blade pitch system are capable of turning the rotor blades about the blade pitch axis.

2.2.2.10 Individual pitch operation

(1) The pitch operation adjusts the blade pitch angles dynamically to optimize the power production and the loading on the rotor blades, drive train and tower.

(2) The individual pitch operation adjusts the pitch angle of every single rotor blade independently.

2.2.2.11 Wind direction and yaw error

(1) The yaw error φ is the angle between the wind direction (instantaneous direction of attack of the wind at hub height) and the rotor axis of the wind turbine, measured in the horizontal plane.

(2) The "cut-out yaw error" φ_A is the largest admissible yaw error (averaging period to be defined by the manufacturer) above which the wind turbine must be shut down immediately.

2.2.2.12 Grid disturbances, grid loss

(1) Deviations from the normal conditions in grid voltage and/or frequency, as mentioned in Section 4.2.5 (grid failures), are defined as grid disturbances or grid loss. Depending on the electrical parameters, the control system decides whether a grid disturbance or a grid loss has occurred. The parameters are defined in a site-specific manner.

(2) The duration of a grid disturbance can vary between 0 seconds and approx. 1–2 minutes. As soon as normal conditions are reached again, the wind turbine continues to operate normally.

2.2.2.13 External power supply, grid failure

(1) By external power supply is meant the supply of any kind of primary or auxiliary power to automation, control or mechanical systems of the wind turbine from outside. Supply of electricity from the grid, external batteries or diesel generators is defined as being an external power supply. Similarly, the external supply of auxiliary forms of power (such as control air, hydraulic system fluid etc.) belongs to the same class.

(2) If energy is obtained by internal conversion of wind energy or kinetic energy of the rotor using the wind turbine's own devices, this does not count as external power supply.

(3) Failure of the external power supply (grid loss) with a duration of up to 6 hours is regarded as a normal external condition. Furthermore, grid loss with a duration exceeding 6 hours up to a duration of 7 days shall be considered and is regarded as an extreme condition.

2.2.2.14 Locking devices

Locking devices are devices which secure the moving parts (e.g. rotor, yaw system, blade pitching system) against any movement.

2.2.3 Requirements and design concept

2.2.3.1 General safety concept

A single failure of any component which is relevant for wind turbine safety, e.g. a sensor or braking system, shall not lead to loss of the safety function. The simultaneous failure of two independent components is classed as an unlikely event, and it is therefore not necessary to consider this. Where components depend on one another, their simultaneous failure shall be classed as a single failure.

Note 1:

By independence is meant that "faults with a common cause" shall rigorously be avoided in the system-engineering design stage. Accordingly, the failure of a single component shall not result in the failure of more than one braking system and thus the loss of the entire safety function.

Note 2:

The procedure given in Section 2.1.4 states how an appropriate level of independency and measures against common-cause failure effects can be achieved.

2.2.3.2 Control system

The control system shall be so designed that it keeps the wind turbine within the normal operating limits under all the external conditions specified in Section 4.2, or returns it to operation within these limits. Malfunctions (such as over-power, overspeed and overheating) shall be detected by the control system and followed by appropriate measures. The control system shall obtain its information from the sensors provided for the wind turbine and shall be able to actuate at least two braking systems. Upon activation of the braking systems by the safety system, the control system shall subordinate itself.

2.2.3.3 Safety system

(1) The safety system shall be operational or in activated mode (triggered) in all modes of the wind turbine, e.g. power production, parked, grid loss or maintenance.

(2) Any function of the safety system shall have a higher priority than the function of the control system.

(3) The safety system shall have access to at least two mutually independent braking systems, independently of any function of the control system.

(4) In addition, the safety system shall have access to equipment for grid disconnection of the generator, independently of any function of the control system

Note:

The separation from the grid need not be carried out at the instant of activation of the safety system. Excessive speeding-up of the wind turbine or operation of the generator as a motor shall be avoided in any case.

(5) The limiting values triggering the safety system shall be defined so that the limit values of the design basis are not exceeded and the wind turbine is not endangered, but also so that the control system is not disturbed unnecessarily by the safety system.

(6) Once triggered by the limiting values, the safety system shall carry out its task without delay, keep the wind turbine in a safe condition and in general initiate deceleration of the rotor with the aid of at least two braking systems.

(7) Once triggered by the limiting values, a clearance of the safety system according to Section 2.2.2.5 is required in any case. If the safety system was triggered before grid loss, then clearance shall not be activated automatically after the return of the grid.

(8) If devices with a programmable controller are used within the safety system, the documentation for the software shall be submitted. The logic of these devices will be assessed by software documentation review and by additional functional testing during the witnessing of commissioning as per Section 10.8.

Note:

Requirements for safety-related software can be found in ISO 13849-1:2006-11, Section 4.6.

2.2.3.4 Braking systems

2.2.3.4.1 Braking system requirements

(1) There shall be at least two mutually independent braking systems by means of which the rotor can be decelerated or brought to a standstill at any time.

(2) In the case of load shedding (e.g. grid loss) and simultaneous failure of one of the braking systems, the remaining braking system(s) must be able to keep the rotor below the maximum overspeed n_{max} (Section 2.2.2.6, para 6) (see also Section 4.3.3.2).

(3) It shall be possible to bring the rotor to a standstill (see Section 2.3.2.15 and Sections 4.3.3.5 and 4.3.3.8).

2.2.3.4.2 Wind turbine with mechanical brake and non-independent blade pitching system

(1) This section applies to wind turbines in which one braking system is a mechanical rotor brake and the other braking system is a blade pitching system, insofar as the blade pitching system is so constructed that a malfunction in a single component can prevent the pitching of all rotor blades (non-independent blade pitching system).

Note:

It is recommended that this Section 2.2.3.4.2 not be applied to new turbine designs. It is intended mainly for the re-certification of existing designs.

(2) If it can be assured that

- the blade pitching system is constantly monitored by a suitable control device which shuts down the wind turbine if the pitching has ceased to function properly, and
- the rotor blades and the pitch system are so designed that, in the event of a breakdown in the mechanism or leaks in the pitch hydraulics, the blades are unable to generate a torque which would accelerate the rotor beyond the maximum overspeed n_{max} (Section 2.2.2.6, para 6) (see Section 4.3.3.2),

it may be assumed that the failure of this braking system (DLC 2.2, Section 4.3.3.2) will occur only at wind speeds up to V_r (Section 2.2.2.8, para 2). Here the fluctuations (gusts) of the wind need to be considered. The magnitude of the gust during operation $V_B = 2 * \sigma_1$ shall be considered, where:

V_B = magnitude of the gust

σ_1 = standard deviation according to Section 4.2.3.1.3

(3) The gust shape shall be assumed according to Section 4.2.3.2.4. Here V_{cg} shall be replaced by V_B and the rise time is T = 2.5 s.

Note:

It shall be observed that the rotor blades may be in a pitch position in which, due to an unfavourable angle of attack, they may generate a torque in excess of the maximum braking moment of the mechanical brake. In this case, the brake shall not become a fire hazard for the wind turbine.

2.2.3.4.3 Selection of the braking principle

At least one of the braking systems should operate on an aerodynamic principle, and as such act directly on the rotor. If this requirement is not met, at least one of the braking systems provided shall act on the parts (hub, shaft) of the wind turbine that rotate at rotor speed.

2.2.3.4.4 Power supply for braking systems

The braking systems shall be so designed that they remain operable if the external power supply (see Section 2.2.2.13) fails. If this requirement cannot be met by all braking systems within the selected system concept, then additional measures that ensure the safety level of this Guideline in an equivalent manner shall be implemented and verified.

2.2.3.4.5 Energy storage for braking systems

(1) If auxiliary power supply from accumulators (e.g. from the hydraulic unit or from batteries) is necessary for the functioning of the brakes, it shall be automatically monitored that a sufficient amount of energy is available for at least one emergency braking.

Note:

If the braking system has also control functions in case of grid disturbances, then the dimensioning of the energy storage shall consider possible grid disturbance events followed by one emergency braking.

(2) Furthermore, Section 2.3.2.11, Section 7.9 and Section 8.6 “Back-up Power Supply System” shall be taken into account.

(3) If the function of the accumulator depends on its temperature, then the accumulator temperature shall be monitored.

(4) If the automatic monitoring of the energy storage cannot be carried out continuously, then automatic tests shall be performed at least weekly to show that a sufficient amount of energy is available. The wind turbine shall be shut down immediately if the automatic monitoring or test yields a negative result.

2.2.3.5 Torque-limiting components

If components are provided to limit torque, any mechanical brake fitted shall be located between the torque-limiting device and the rotor hub.

2.3 Protective and Monitoring Devices

2.3.1 General

(1) The safety system is activated when limiting values are exceeded. This initiates a braking process. The requirements on when a malfunction is to activate the safety system directly and/or how it is to be treated by the control system are given below.

(2) In Appendix 2.A of this chapter, the interaction of control system and safety system is represented graphically as a typical example.

2.3.2 Limiting values, control system

2.3.2.1 General

In some cases defined here in Section 2.3.2, the wind turbine is permitted to start up again automatically without clearance following a turbine shut-down. This automatic start-up is limited to a few times every 24 hours for exceedance of most of the limiting values. It is in keeping with this section that the transgression counts for the different limiting values can be undertaken independently of each other.

2.3.2.2 Rotational speed

2.3.2.2.1 Measurement of rotational speed

The rotational speed shall be picked up at least twice by separate systems, and supplied at least twice to the control system and at least once to the safety system. At least one of the speed sensors shall be mounted on a component of the wind turbine that runs at rotor speed.

Note:

Any automatic triggering of the blade tip brakes shall be reported to both the safety system and the control system. If that is not possible, it shall be ensured that the blade tips do not engage again and the rotor rotational speed then exceeds n_A *again (see Section 2.2.2.5, para 5).*

2.3.2.2.2 Operational reliability of the measurement system

(1) As a matter of principle, the speed measurement systems shall meet the same requirements regarding functionality and reliability as the braking system. In particular, the location of the sensors shall meet this requirement.

(2) The control system shall continuously monitor the plausibility of at least two of the measured speeds with regard to each other in all operational modes of the wind turbine, except modes with stopped or idling rotor.

2.3.2.2.3 Excessive speed and the reaction of the control system

(1) If the rotor speed exceeds the operating range (Section 2.2.2.6, para 1) ($n > n_3$), then the control system shall initiate a deceleration of the rotor.

(2) If the rotational speed n_4 (Section 2.2.2.6, para 4) is exceeded, then the control system shall shut down the wind turbine.

(3) If the monitoring of the mutual speed plausibility detects an error, the wind turbine shall be shut down.

(4) Following a shut-down, an automatic re-start may take place without clearance if this is provided for in the system concept and no safety-relevant fault can be detected. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.2.4 Rotational speed exceeding activation speed

If the activation speed n_A (Section 2.2.2.6, para 5) is exceeded, the safety system shall be activated immediately.

Note:

For the speed rating requirements of the generator, see Section 8.2.2.

2.3.2.2.5 Behaviour following activation of the safety system

(1) If the safety system has responded after excessive speed according to Section 2.3.2.2.4, the maximum overspeed n_{max} (Section 2.2.2.6, para 6) shall not at any time be exceeded (not even briefly). This shall be taken into consideration particularly for aerodynamic brakes and for brakes whose action is staggered in time.

(2) The safety system shall shut down the wind turbine immediately and bring it into a safe condition.

2.3.2.3 Power

2.3.2.3.1 Measurement of power

(1) Power measurement shall be regarded as an operational measurement and treated accordingly.

(2) The measured power in combination with the rotational speed is regarded as a measure of the average loading of the wind turbine.

(3) Generally, the active electrical power shall be used as the measurement parameter. If the system concept includes the possibility of the over-power P_T according to Section 2.2.2.7, para 2, being exceeded, the power shall be picked up as a control parameter and supplied to the control system.

(4) The power measuring equipment shall be capable of picking up both average values (about 1–10 minute mean) and short-term power peaks (sampling rate at least once per second).

(5) For wind turbines with a rated power of 1 MW or more, see also Section 2.3.2.3.4.

2.3.2.3.2 Exceeding the over-power P_T or the rated power P_r

(1) If the power exceeds the over-power P_T, then the corresponding measures shall be initiated automatically by the control system without delay. The long-term average of the power shall not exceed the rated power P_r (Section 2.2.2.7, para 1).

(2) The measures to be taken depend on the system concept. The power shall be reduced accordingly or the wind turbine shall be shut down.

(3) The value for the over-power P_T shall be defined by the manufacturer together with the averaging periods, and taken into account appropriately in the load calculation (fatigue loads). During the prototype test, it shall be shown that the defined values are met.

Note:

As a rule, P_T should lie directly above the rated power P_r or be equal to it.

(4) If the wind turbine was shut down after exceeding the over-power P_T an automatic re-start may take place without clearance if this is provided for in the system concept and no safety-relevant fault can be detected. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.3.3 Exceeding the activation power P_A

(1) The power shall be monitored continuously for exceeding of the instantaneous activation power P_A. If the instantaneous power exceeds the activation power P_A (Section 2.2.2.7, para 3), protective measures shall be initiated automatically without delay and the safety system shall be activated.

(2) The actual measures depend on the system concept. In all cases, the wind turbine shall be shut down by the safety system and brought into a safe condition.

(3) The value for the activation power P_A shall be defined by the manufacturer of the wind turbine and taken into account correspondingly in the load calculation.

2.3.2.3.4 Redundancies in measurement

(1) In the case of wind turbines with a rated power of 1 MW or more, this monitoring and the measurement devices needed for the task shall be provided in redundancy to the power measurement of the control system. This monitoring system shall activate the safety system directly in case of exceeding the activation power P_A.

(2) An exception can be made from the provisions if the required redundancy in power measurement is given in some other manner.

(3) The required redundancy can be achieved by separate monitoring of the electrical current in the main power distribution path. In case of exceeding the defined limits, the wind turbine shall be shut down. A clearance according to Section 2.2.2.5 is required. The shut-down limits shall be considered in the load calculations.

(4) The required redundancy can be also achieved by a separate monitoring of mechanical torque in the drive train. If the monitoring of the mechanical torque is achieved by a friction clutch, the activation of this clutch shall be detected and the wind turbine shall shut down. A clearance according to Section 2.2.2.5 is required. The shut-down limits shall be considered in the load calculations.

2.3.2.4 Wind speed

2.3.2.4.1 Requirements

If safe operation of the wind turbine depends on wind speed measurements, or if wind speed is one of the input parameters to the control system, a reliable and appropriate means of measuring wind speed shall be provided.

2.3.2.4.2 Measurement of wind speed

(1) If measurement of wind speed is necessary as described in Section 2.3.2.4.1, this requirement can be met by measuring the speed either directly or via another parameter with a clear and recognized relationship to it, which is then processed. As a matter of principle, suitable sensing points and measurement techniques shall be selected for operational measurements. The wind speed at hub height – with flow as undisturbed as possible – is to be considered as the relevant measurement parameter.

(2) A continuous plausibility check of the measured values (e.g. by comparison with other measurands related to wind speed) is required.

(3) Equipment of the sensor with a suitable heating which will be activated in case of the danger of icing is recommended.

2.3.2.4.3 Exceeding the cut-out wind speed

If a cut-out wind speed V_{out} according to Section 2.2.2.8, para 3, has been used as a basis for the wind turbine design, the wind turbine shall be shut down immediately and automatically by the control system if this limiting value is exceeded.

2.3.2.4.4 Exceeding the short-term cut-out wind speed

If a cut-out wind speed has been used as a basis for the wind turbine design, the wind turbine shall be shut down immediately and automatically by the control system if the short-term cut-out wind speed V_A according to Section 2.2.2.8, para 4, is exceeded.

2.3.2.4.5 Automatic start-up

If the wind turbine was shut down after exceeding a cut-out wind speed, an automatic re-start may take place without clearance if the wind speed has fallen to a permissible value according to the system concept and no safety-relevant fault can be detected.

2.3.2.4.6 Control during faulty wind speed measurements

If the control system detects that the wind speed measurements yield faulty results, the wind turbine shall be shut down.

2.3.2.5 Blade pitch angle

2.3.2.5.1 Measurement of pitch angle

(1) For pitch-controlled wind turbines, the monitoring of the blade pitch angle shall take place continuously.

(2) The blade pitch angle of each rotor blade shall be monitored for wind turbines with an independent blade pitching system.

2.3.2.5.2 Operational safety

(1) The measurement of the blade pitch angle shall be protected effectively against external influences.

(2) The control system shall monitor the plausibility of the measured blade pitch angles. If these monitoring tasks cannot be carried out continuously, then automatic tests shall be performed at least weekly. The wind turbine shall be shut down immediately if the monitoring or a test reveals a negative result. Furthermore, Section 2.3.2.11 shall be taken into account.

2.3.2.5.3 Exceeding the limiting values

(1) If the blade pitch angle of any rotor blade exceeds the limiting values for the deviation between the demanded value of the pitch angle and the currently measured pitch angle, the wind turbine shall be shut down by the control system.

(2) If the deviation between the pitch angles exceeds the limiting value, the wind turbine shall be shut down by the control system (see Section 2.3.2.5.1, para 2).

(3) If the wind turbine was shut down after exceeding the limiting value, an automatic re-start may take place without clearance if this is provided for in the system concept and if no safety-relevant fault can be detected. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.6 Individual pitch operation

2.3.2.6.1 Requirements

(1) If the wind turbine uses individual pitch operation (see Section 2.2.2.10) for adjusting the blade pitch angles dynamically, a reliable and appropriate arrangement shall be provided for measuring all values required by this control function.

(2) The averaging periods in the signal processing and the sensitivities, as well as the mounting points of the sensors for the individual pitch operation, shall be so selected that all relevant values are measured reliably.

2.3.2.6.2 Operational safety

(1) The measurement of the critical values for the individual pitch operation shall be self-monitoring or redundant. These critical values for the individual pitch operation may be the blade or the main shaft bending moment, the rotor position as well as the blade pitch angle.

(2) In case of malfunction of the individual pitch operation, the control system shall shut down the wind turbine or change to a reduced operational mode. Depending on the type of malfunction, the wind turbine may then re-start automatically or be re-started by remote intervention. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.7 Shock

2.3.2.7.1 General

By shock is meant forced movements and accelerations of the wind turbine, as caused by damage, imbalance or other influences (e.g. earthquakes).

2.3.2.7.2 Measurement of shock

Monitoring for shock shall take place continuously, with the measurement being compared to the limiting value. The sensor shall be located at nacelle height, eccentric to the tower axis. As the shock to be sensed is generally noticeable as a movement of the whole nacelle, measurement techniques sensing the total movement shall be used. If the nacelle movement is not transmitted to the tower, a suitable relative movement may be sensed as a substitute.

2.3.2.7.3 Operational safety

The sensitivity of the sensor shall be matched to the conditions prevailing. It shall be protected effectively against all external influences, including interference by unauthorized persons. It is recommended that the sensitivity be set when the wind turbine is running.

2.3.2.7.4 Exceeding the limiting value

If the shock actually measured exceeds the limiting value (to be determined beforehand), the safety system shall be activated and shall shut down the wind turbine.

2.3.2.8 Operational vibration monitoring

2.3.2.8.1 Requirements

(1) By vibration is meant forced cyclic movements of the wind turbine, as caused e.g. by imbalance or by operating the wind turbine in the vicinity of a natural frequency of components. Imbalance may point to damage, malfunction (e.g. asymmetric pitching of the rotor blades) or other external influences (e.g. wind shear).

(2) The operational vibration monitoring in accordance with this section may be essential for:

- pitch-controlled wind turbines (see para 3)
- wind turbines operating in the resonance range close to the natural frequency of the tower (see para 4)
- wind turbines for which aerodynamically related blade vibrations cannot be ruled out (see para 5)

(3) In principle, it cannot be ruled out that cyclic collective pitch movements might excite cyclic movements of the tower head, therefore operational vibration monitoring is required for pitch-controlled wind turbines.

(4) The operational vibration monitoring in accordance with this section is one of the requirements for operation of the wind turbine in the resonance range close to the natural frequencies of the tower (see Section 6.6.5.1, para 5).

(5) In the case of wind turbines for which aerodynamically related blade vibrations cannot be ruled out, operational vibration monitoring according to this section may be necessary (in addition to the vibration monitoring of the tower, if applicable).

2.3.2.8.2 Measurement of vibrations

(1) The vibrations shall be measured constantly and their magnitude compared with the limiting values to be determined beforehand.

(2) The averaging periods in the signal processing and the sensitivities, as well as the mounting points of the sensors, shall be so selected that all loading-relevant movements of the components to be monitored are measured reliably.

(3) The measurement and signal processing can be performed in the control system.

2.3.2.8.3 Determination of the limiting values

(1) The limiting values for the vibration monitoring shall be so determined that the loads and/or movements defined in the design of the wind turbine for the components to be monitored are not exceeded. The vibration level determined during the design of the wind turbine shall be taken as the basis.

(2) Limiting values shall be defined for short-term monitoring (e.g. measurement period up to a few seconds) and for long-term monitoring (e.g. measurement period in the range of several minutes).

Note:

It is advisable to define these limiting values in relation to the operating condition of the wind turbine (e.g. wind speed, rotational speed, or power).

(3) The effectiveness of these criteria shall be verified, e.g. through simulations.

Note:

For these simulations, malfunctions (e.g. mechanical and/or aerodynamic imbalance of the rotor, displacement of natural frequencies) can be defined, depending on the system concept and tower design. In the simulations, it shall then be shown that these malfunctions are detected by the vibration monitoring with the selected sensitivities, averaging periods and limiting values, without exceeding the loads defined for the design.

2.3.2.8.4 Exceeding the limiting value

If the currently measured vibrations exceed one of the defined limiting values, the wind turbine shall be shut down by the control system.

2.3.2.8.5 Automatic start-up

Following a shut-down in accordance with Section 2.3.2.8.4, an automatic re-start may take place without clearance if this is provided for in the system concept and if no safety-relevant fault can be detected. The automatic start-up shall be limited to three times every 24 hours.

2.3.2.9 Grid loss / load shedding

2.3.2.9.1 General

Should a wind turbine lose its load (e.g. grid loss), the rotor may speed up very rapidly. This endangers individual components and the structural integrity of the entire wind turbine.

2.3.2.9.2 Operation following grid loss / load shedding

If there is a grid loss, or if a wind turbine has lost its load for other reasons, this shall be detected by the control system and the control system shall bring the wind turbine into a safe condition.

2.3.2.9.3 Operation after restoration of grid

Grid loss is considered an external event. For that reason, the wind turbine may be re-started automatically by the control system once the grid is capable of taking power again.

2.3.2.10 Short circuit

2.3.2.10.1 Requirements

The wind turbine shall be equipped with suitable short-circuit protection devices (see Section 8.7.3). The protection devices in the main electrical power distribution path shall fulfil Section 2.3.2.10.2.

2.3.2.10.2 Operation following a short circuit

(1) If the protection devices detect a short circuit, they shall respond and simultaneously trigger the safety system.

(2) The safety system shall shut down the wind turbine and bring it into a safe condition.

Note:

If an automatic reset of the protective devices is not possible (e.g. in the case of fuses), a shut-down by the control system is sufficient if the wind turbine achieves a safe condition.

2.3.2.11 Condition monitoring of the braking systems

2.3.2.11.1 General

The braking systems according to Section 2.2.3.4 are of particular relevance as regards safety. Mechanical braking systems are subject to a high degree of wear. For that reason, the operational brake should as far as possible operate on a low-wear or no-wear principle (see Section 2.2.3.4.3). Should the design of the braking system of a wind turbine permit the possibility of increased, unnoticed wear or a malfunction in the necessary accumulator (see Section 2.2.3.4.5) resulting in failure to respond when required, then monitoring of the condition of the braking equipment shall be provided.

2.3.2.11.2 Measurement parameters

The brake lining thickness and/or the brake slack in mechanical brakes, and also, depending on the design concept, the time to effect the braking or the power consumption, are all factors that can be used as relevant measurement parameters for condition monitoring. Accumulators shall be monitored in accordance with their design (see Section 2.2.3.4.5). For blade pitch angle measurement, see Section 2.3.2.5.

2.3.2.11.3 Safety requirement

If condition monitoring is provided, it shall meet the same safety standards as the braking system itself (i.e. the brake shall respond if the monitoring fails). The response of the condition monitoring equipment shall be such that possible progressive defects are detected early – at any rate before the required braking power can no longer be achieved – and countermeasures are initiated.

2.3.2.11.4 Operation after a fault is detected

If the condition monitoring detects that a braking system is not ready for operation, the wind turbine shall be shut down by the control system. An unambiguous report of the failure detected shall be made. An automatic re-start of the wind turbine is not permissible.

2.3.2.12 Cable twisting

2.3.2.12.1 General

If operation of the wind turbine may result in twisting of flexible cables, particularly the connecting cables between rotating parts (nacelle) and parts of the fixed structure (tower or foundation), technical measures shall be taken to prevent destruction of these cables by excessive twisting.

2.3.2.12.2 Monitoring of the control system

Direction-dependent counting or a similar procedure for identifying the total revolutions of the nacelle shall be regarded as an appropriate measurement parameter for the twisting of flexible cables.

2.3.2.12.3 Monitoring of the safety system

The maximum acceptable degree of twisting for the flexible cables shall be defined by the manufacturer or supplier. The measurement of this value shall be independent of the measurement as per Section 2.3.2.12.2.

2.3.2.12.4 Operation to avoid excessive twisting

(1) In the case of wind turbines with active yaw systems, untwisting of the cables can be undertaken automatically by the control system through appropriate operation of the yaw drive. During the untwisting, the wind turbine shall be shut down. After the flexible cables have been untwisted automatically, the wind turbine can be re-started automatically without clearance.

Note:

*To prevent possible danger to the wind turbine structure, it may be advisable to suppress the automatic untwisting at extremely high wind speeds (e.g. V ≥ 0.8 * Vref) and to have the yaw system control the wind turbine automatically until these wind speeds have dropped to an acceptable level.*

(2) If the maximum acceptable degree of twisting is exceeded without any response from the control system, the safety system shall shut down the wind turbine and bring it into a safe condition.

(3) In the case of wind turbines without active yaw systems, further rotation of the nacelle shall be prevented after the maximum acceptable degree of twisting (see Section 2.3.2.12.3) has been reached. The wind turbine shall be brought into a safe condition.

2.3.2.13 Yaw system

2.3.2.13.1 Measurement of wind direction

If the measurement of wind direction is necessary for the control of the wind turbine, the measurement equipment (e.g. wind vane) shall be constantly monitored in a suitable way and equipped with a proper heating which shall be activated upon the danger of icing.

2.3.2.13.2 Operation for faulty wind direction measurements

If the control system detects that the wind direction measurements yield faulty results, the wind turbine shall be shut down.

2.3.2.13.3 Active yaw system

(1) In the case of nacelles with active yaw systems, it shall be ensured that even straightforward manual maloperation cannot produce conditions which put the integrity of the wind turbine at risk as a result of stresses not included in the calculations. The drive of nacelles with active yaw systems shall be provided with a braking system. Before starting, it shall be established unequivocally that the position of the nacelle conforms to the wind direction of the design.

Note:

This can be of particular importance after a lengthy standstill, for instance, if the wind has veered something like 180° since the time of shutting down and the wind direction is not followed with the wind turbine at standstill.

(2) If a cut-out yaw error φ_A (see Section 2.2.2.11, para 2) was defined in the system concept, the wind turbine shall be shut down immediately when this value is exceeded. Once the yaw error is again within the permissible range, the wind turbine can be re-started automatically without clearance.

2.3.2.13.4 Passive yaw system

In case of a passive yaw system, it shall be established unequivocally before start-up that the position of the nacelle conforms to the wind direction of the design.

2.3.2.14 Frequency and voltage

(1) In the case of wind turbines operating in parallel with the grid, a fixed grid frequency is assumed. As a rule, the grid frequency is imposed on the wind turbine. Specific monitoring and control is necessary to the extent required by the relevant grid operator to maintain satisfactory parallel operation. Apart from that, Section 4.2.5 shall apply.

(2) In wind turbines operating in a stand-alone mode, on the other hand, the frequency is often determined by the wind turbine itself. Whether and to what extent frequency variations can be tolerated should be determined by taking the individual service into consideration. In general, however, designs should not be based on deviations greater than ± 5 % or ± 10 % for short periods.

2.3.2.15 Emergency stop

2.3.2.15.1 General

(1) The emergency stop is a complementary protective measure that is not a primary means of risk reduction for hazards in wind turbines.

(2) At least one emergency stop button shall be provided at the foot of the tower and one in the nacelle as a possibility for manual intervention. The position and design of the emergency stop buttons shall be in compliance with standards for an appropriate usage (see ISO 13850, IEC 60204-1, IEC 60947-5-5).

Note:

If, in addition to this GL Guideline, the international standard IEC 61400-1, Edition 2005, is to be fulfilled, then Section 8.3 (page 47) of this standard should be considered.

2.3.2.15.2 Emergency stop requirements

(1) The emergency stop buttons shall be available and functional at all times. Triggering the emergency stop function must override all other functions and operations in all modes of the wind turbine. Safety measures or other safety functions shall not be displaced or affected by the emergency stop function.

(2) The misuse of the emergency stop buttons (for example, switching off for maintenance) shall be avoided.

(3) The emergency stop function shall activate the safety system and bring the rotor of the wind turbine to a standstill in the shortest time under all wind conditions below the wind speed V_T (see Section 4.3.3.8, para 1). The primary aim is not a gentle stop but rather the most rapid braking to a standstill that is compatible with the strength of the wind turbine.

(4) The emergency stop shall function either as a stop category 0 or as a stop category 1 according to IEC 60204-1, Section 9.2.5.4.2.

Note:

It may be necessary, after triggering the emergency stop function, to allow further operation of auxiliary equipment, e.g. cooling, lubrication, aviation lights and service lifts.

2.3.2.15.3 Emergency stop reset

The reset of the emergency stop function shall be possible only by a manual action at that location where the command has been initiated. A reset of the emergency stop function shall not re-start the wind turbine but only permit re-starting.

2.3.2.16 Faults in main components

(1) Machinery components shall be monitored according to the state of the art. Such monitoring equipment shall cover physical parameters which can be used as a measure of reliable operation (e.g. gear oil pressure, gear oil temperature, bearing temperatures, generator winding temperature etc.). The extent to which such equipment shall be provided depends essentially on the overall design concept.

(2) When limiting values are exceeded, the control system shall shut down the wind turbine or change into a reduced operational mode. Depending on the type of malfunction, the wind turbine may then re-start automatically or be re-started by remote intervention from the control room. The automatic start-up shall be limited to three times every 24 hours.

(3) In the design of the control system concept, the structural integrity of the wind turbine shall be given priority over its availability.

2.3.2.17 Operation of a cold wind turbine

If a relationship between component temperature and the maximum admissible power transmission is specified by the manufacturer for certain components of the wind turbine (e.g. gearing, generator, transformer), then a corresponding “warm-up phase” shall be provided in the control system of the wind turbine. The power provided by the rotor shall at no time be permitted to be larger than the maximum specified for the momentary temperature by the manufacturer of the corresponding component.

2.3.2.18 Operativeness of the control system and data storage

(1) The control concept is defined as the procedure for operating the wind turbine under the specified conditions (see Section 2.2.2.1). If the control is carried out by a programmable control system, this takes over control and regulation of the wind turbine.

(2) If different parts of the control system (e.g. different programmable logic control units in the hub and the nacelle) that are each important for safe turbine operation lose their mutual communication, then both parts shall initiate a turbine shut-down.

(3) If the control system detects that it has lost control of the wind turbine (e.g. a demanded stop procedure is not executed), the control system shall trigger the safety system.

(4) The control system shall be monitored by a suitable arrangement (e.g. watchdog). If this is triggered, the wind turbine shall be shut down immediately. If this monitoring arrangement responds more than once in 24 hours, the safety system shall also be triggered.

(5) If the safety system is triggered in the case of wind turbines with a rated power of 1 MW or more, the control system shall store the data of the final operating conditions.

2.3.2.19 Automatic ice detection

2.3.2.19.1 General

(1) A system which automatically detects the formation of ice on components of the wind turbine can be certified.

(2) This Section 2.3.2.19 refers to wind turbines without blade heating systems.

2.3.2.19.2 Ice sensor

(1) The sensor has to be capable of detecting icing or an ice-forming atmosphere at least on the level of the hub height. This is to be verified by tests or data sheets of the sensor manufacturer.

(2) The sensor and the evaluation processor unit have to possess a suitable monitoring arrangement which signalizes possible faults.

2.3.2.19.3 Operation in case of icing or malfunction

The signals “ice-forming atmosphere exists” and/or “icing” as well as “malfunction of ice sensor“ have to be available for the wind turbine control system all the time. The wind turbine shall be shut down if

- the ambient temperature is below + 5 °C and simultaneously
- one of the signals “ice-forming atmosphere exists”, “icing” or “malfunction of ice sensor“ occurs or the communication to the ice sensor is not available.

For this purpose, it is necessary to always monitor the complete communication channel from the ice sensor to the wind turbine control (as the case may be, including the park communication, if this is used for transmission of the signal).

2.3.2.19.4 Plausibility test for icing

(1) Due to the fact that the sensor cannot monitor the complete rotor blades for icing, a plausibility test in the control system is additionally required. This test can e.g. consist of an examination of the plausibility of wind/power (including pitch angle and speed) at all wind speeds for which the wind turbine is in production operation. The parameters and limit values shall be specified.

(2) The function of the anemometer and the wind direction sensors shall be monitored.

(3) The wind turbine shall be shut down by the control system if the plausibility test reveals a negative result.

2.3.2.19.5 Re-start of the wind turbine

After a shut-down according to Section 2.3.2.19.3 or 2.3.2.19.4, the wind turbine shall only be started after inspection shows that there is no ice on the rotor blades. An automatic re-start can be performed if it is ensured that the rotor blades are ice-free. The method to ensure this shall be agreed upon in each individual case under consideration of the risk potential.

2.3.2.19.6 Function tests and maintenance of the ice sensor

(1) During commissioning of the wind turbine and during its maintenance, the necessary procedures shall be carried out according to the specifications of the sensor manufacturer.

(2) In addition, the sensor and the wind turbine behaviour shall be tested (see Section 9.2 and 9.4).

2.3.3 Safety equipment (locking devices) for maintenance

2.3.3.1 Requirements

A wind turbine shall be equipped with at least one lock or equivalent device each for the rotor, yaw system and blade pitching system (see Section 2.2.2.14), with the function of locking these against movement. Automatic activation (automatic engagement on reaching standstill) is not necessary in general.

Note:

Braking equipment may not, as a rule, be regarded as constituting the required locking device at the same time. Deviation from this rule is possible in exceptional cases, provided the system design ensures that work on each part of the braking system can be carried out safely. Work on a braking system can be carried out safely only if all rotation of the parts of the wind turbine which the system is intended to brake can be reliably prevented.

2.3.3.2 Design of the locking devices

(1) The locking devices shall be so designed that even with a brake removed they can reliably prevent any rotation of the rotor, nacelle or the rotor blade. The design of the locking devices shall be based on Section 7.5. It shall have provisions for safe unlocking.

(2) The rotor lock shall be arranged to act on the drive train near the hub, and a form-fit is recommended for the rotor lock.

Note:

If it can be ensured that during the lifetime of the wind turbine (erection, operation, maintenance) the rotor locking device is only applied when qualified personnel with technical training is present at the wind turbine, the rotor lock can be dimensioned for DLC 8.1 only (see Section 4.3.3.8).

2.3.3.3 Safety requirements

The design of the locking device shall be based on the assumption that people deliberately enter, remain in and work in a hazardous area with confidence in the functioning of the device. Particularly high requirements shall thus be imposed as regards the operational safety, quality and accessibility of the device, as well as its engagement with the parts of the wind turbine being locked (e.g. rotor blades, hub, shaft).

2.3.3.4 Activation of the locking device

If work is to be carried out on those parts of the wind turbine which rotate during operation, the locking device shall always be activated. It shall also be activated even if the wind turbine is held stopped by the brake capable of slowing the rotor to a standstill, or any azimuth brakes that may be provided. An appropriate note shall be inserted in the instructions (see chapter 9).

Appendix 2.A Interaction of the Control and Safety Systems

This sketch visualizes schematically the interaction of the control and safety systems and is intended to be helpful for understanding the wording in Chapter 2. However, the wording of Chapter 2 is binding.

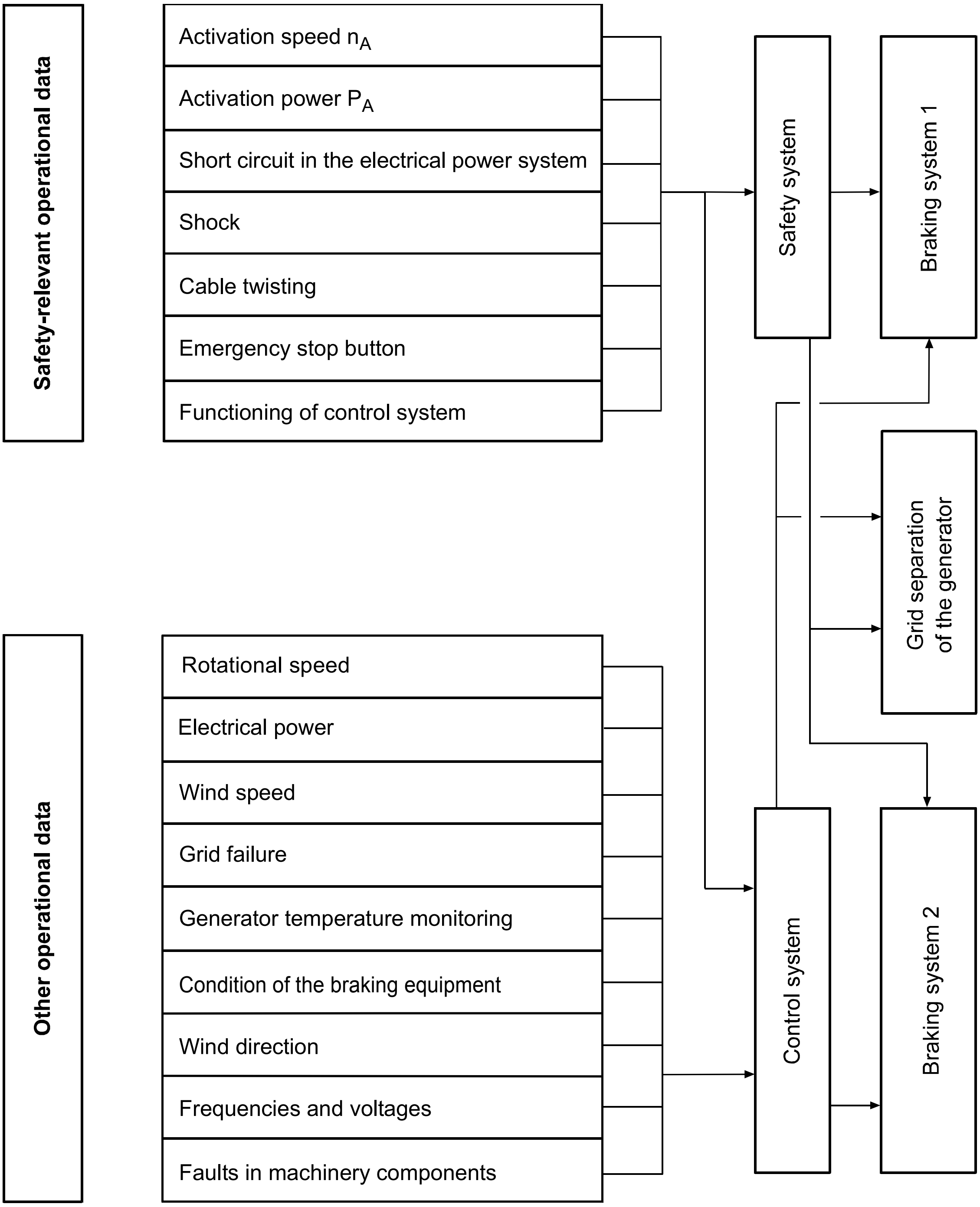

Fig. 2.A.1 Interaction of the control and safety systems

Appendix 2.B Load assessment relevant data

The tables below provide a summary of the main load assessment relevant parameters as defined in Chapter 2. They are meant as an expedient for data submission for the load assessment. The use of the tables is optional.

Table 2.B.1 Turbine data relevant to load assessment

	Item no.	GL Guideline reference	Item	Unit	Value(s)	Reference (in case of external documentation)
Rotor speed, referred to ☐ LSS ☐ HSS	1.1	-	Gearbox ratio	-		
	1.2	2.2.2.6 (1)	Operating range n_1 – n_3	1/min		
	1.3	2.2.2.6 (2) / (3)	Rated rotor speed Set value of speed controller n_r/n_2	1/min		
	1.4	2.2.2.6 (4)	Cut-out rotor speed n_4	1/min		
	1.5	2.2.2.6 (5)	Activation speed n_A	1/min		
	1.6	2.2.2.6 (6)	Max. overspeed, n_{max}	1/min		
Electrical power output and torque	2.1	2.2.2.7 (1)	Rated electrical power output, P_r	kW		
	2.2	2.2.2.7 (2)	Over-power, P_T	kW		
	2.3	2.2.2.7 (3)	Activation power, P_A	kW		
	2.4	-	Slip torque of slip coupling incl. tolerance	kNm		
	2.5	8.7.2 Appendix 4.C	Maximum generator torque during short circuit	kNm		
Wind speed	3.1	2.2.2.8 (2)	Rated wind speed, V_r	m/s		
	3.2	2.2.2.8 (3)	Cut-out wind speed, V_{out}	m/s		
	3.3	2.2.2.8 (4)	Short-term cut-out wind speed, V_A	m/s		
	3.4	4.3.3.8 (1)	Max. 10min-mean wind speed for maintenance V_T	m/s		
Mechanical brake	4.1	7.5.1 (6)	Min. required / max. braking torque, M_{Bmin} / $M_{Bmax.}$	kNm		
	4.2		Time delay for activation of the mechanical brake	s		
	4.3		Ramp time (time constant) for braking torque	s		
Aerodynamic brake, pitch system	5.1		Min./max. pitch or blade-tip angle (hardware stop)	°		
	5.2		Pitch angle after normal stop / grid loss	°		
	5.3		Max. difference between pitch angles of blades before shut-down	°		
	5.4		Max. pitch- / tip-speed at emergency stop	°/s		
	5.5		Max. pitch speed during operation	°/s		
	5.6		Time delay for activation of pitch movement	s		
Wind tracking	6.1		Min./max. yaw-braking torque	kNm		
	6.2		Max. yawing speed	°/s		
	6.3		Max. yaw error for shut down φ_A	°		
	6.4	4.3.3.8 (1)	Max. allowed yaw error at V_T	°		
	6.5		Min. yaw error for triggering yawing activity	°		
	6.6		Averaging time of yaw error for triggering yaw activity	s		
	6.7	4.3.3.6.(8)	Uninterruptible power supply (UPS) for yaw system	yes / no		
Temperature	7.1	4.2.4.1	Min. / max. ambient temperature during operation	°C		
Nacelle vibration	8.1	2.3.2.8	Max. acceleration	m/s²		

Table 2.B.2 Shut-down parameters relevant to load assessment

Quantity	Referring to item no.	Value or status	Averaging time for triggering	Time delay for action	Action				Reference for external documentation (if applicable)
					Pitch state	Generator state	Mechanical brake state	Yaw state	
Rotor speeds	1.4	n_4=							
	1.5	n_A=							
		n_x=							
Power	2.2	P_T=							
	2.3	P_A=							
		P_x=							
Wind	3.2	V_{out} =	(e.g. "3sec mean" or "immediately" ...)	(e.g. "0.2sec")	(e.g. "8°/s to position of 90°" ...)	(e.g. "generator switched off immediately" or "stays online until ...")	(e.g. "mech. brake applied at rotor speed < = > ... rpm")	(e.g. "still enabled" or "disabled" or "yaw rate= ...")	
	3.3	V_A=							
Pitch system		Pitch runaway							
	5.3	Pitch angle difference between blades							
		Difference between actual pitch angle and scheduled value							
		(Other possible pitch failures ...)							

Table 2.B.2 Shut-down parameters relevant to load assessment (continued)

Yaw	6.3	φ_A=							
		(Further yaw failure(s), ...)							
Electrical system		Grid loss							
	2.5	Generator short circuit							
Emergency stop		Em. stop button							
Nacelle vibration	8.1								
:		:							

"quantity" should be filled according to the safety and control system of the turbine
"trigger value or failure" according to GL Guideline plus definitions by the manufacturer
"averaging time" as appropriate, e.g. "immediately", "3sec mean", "10min mean", ...
"time delay for action" as appropriate, e.g. "immediately" or "0.2sec" ...
"pitch state" should include the appropriate pitch rate and the final pitch position
"generator state" should specify whether the generator remains online or is switched off, electrical power is ramped down (how?) etc.
"mechanical brake state" should specify whether the mechanical brake is activated immediately, delayed, ramped up, not activated, ...
"yaw state" should specify whether the yaw system is still active, disabled, shows any defined action …
subscript "x" means to be specified, if applicable, by the manufacturer

Appendix 2.C List of Protection Functions (Example)

In the following, a list of protection functions is given to show an example and the possible format of such a list. The list shall not be seen as a list of requirements. Additional and/or other items may be necessary, depending on the wind turbine design.

Protection function (example)	Required performance level (example)
Protection against excessive rotor speed	d
Protection against excessive power production	d
Protection against short circuit	d
Protection against wrong pitch angle	d
Protection against rotor blade exceeding the 90° pitch angle	d
Shut-down in case of excessive shock	d
Protection against excessive cable twisting	d
Shut-down to standstill in case of emergency stop button activation	d
Protection against hazardous effects of faults in the control system	d
Protection against operation at excessive wind speed	d
Shut-down after grid loss	d
Protection against excessive generator temperature	c
Shut-down at unacceptable brake wear	c
Protection against incorrect wind direction measurements	d
Protection against faults in machinery components (e.g. oil temperatures, oil pressure, vibration from worn machinery components, …); necessity depending on the application	c

Rules and Guidelines
IV Industrial Services

1 Guideline for the Certification of Wind Turbines

3 Requirements for Manufacturers, Quality Management, Materials and Production

Edition 2010

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3.1 Requirements for Manufacturers

3.1.1 General

(1) Manufacturers shall verifiably be suitable for the work to be carried out as regards their workshop facilities, manufacturing processes as well as training and capabilities of the personnel. Proof of this may be provided by means of a documented and certified quality management system (see Section 3.2). If required, GL will issue a shop approval on request of a manufacturer, provided the approval conditions are fulfilled (see Section 3.1.4).

(2) It is the responsibility of the manufacturer to observe and conform to this Guideline, the pertinent laws and ordinances, technical regulations, standards and data sheets, such as those from the chemicals industry etc. (see also Section 3.2.1, para 2).

(3) Insofar as the requirements for the manufacturers set out below (especially as regards quality control) are not further defined, these shall be defined in accordance with the quality management requirements (see Section 3.2). Details shall be agreed with GL for each individual case.

3.1.2 Works equipment

(1) The manufacturers shall have at their disposal suitable facilities and equipment for faultless execution of the work. External facilities may be included for consideration only if these meet the prerequisites for competent execution and are available without restriction.

(2) Equipment and facilities include, on the scale necessary for the manufacture in question, for instance the following:

- workshops, roofed-over working areas as required, equipment for assembly sites
- store-rooms for materials and components
- drying facilities (e.g. for wood, welding fillers etc.)
- lifting gear for assembly and transport
- processing machinery and tools
- tools and equipment for welding and cutting
- appliances for joining-up, and for welding, laminating, bonding and glueing
- air-condition monitoring instruments
- facilities for preheating and heat treatment
- test equipment and materials plus means for their calibration

3.1.3 Personnel

(1) The personnel employed by the company shall be such as to ensure that the components can be competently prepared, manufactured and tested to the extent necessary. GL may require proof of the technical qualifications of the staff.

(2) The respective areas of responsibility shall be laid down and arrangements made for deputies for those responsible.

3.1.4 Shop approval

3.1.4.1 General

Shop approval is required for laminating and bonding. Shop approvals by other organizations can be recognized after consultation with GL. GL reserves the right to require approval for other manufacturing methods or working techniques.

3.1.4.2 Application for approval

(1) Application for approval shall be made on a form provided by GL on request. Any additional information, documents and explanations demanded or necessary (see Sections 3.2, 3.3 and 3.4) shall be enclosed with the application.

(2) The application shall describe the organization and technical facilities of the company, as well as provide information about personnel qualifications, scope of production and production processes plus quality control.

(3) GL shall be notified of the individuals responsible for observation of the approval conditions and for the quality of the products manufactured, and of their deputies.

(4) The tests which are in the manufacturer's responsibility shall be documented. This may be acknowledged within the context of a certification of the quality management system (see Section 3.2).

3.1.4.3 Approval procedure, period of validity

(1) After GL has checked the application for compliance with the requirements of Sections 3.3 and 3.4 and has inspected the works, the shop approval may be granted for a period of up to three years. If work under the surveillance of GL is carried out continuously during the period of validity, this can be extended without further checks on request by the manufacturer.

(2) If no work under the surveillance of GL has been carried out for more than one year, prolongation shall be applied for no later than the expiry of the three-year period of validity. Updated documentation shall be enclosed with the application. In this event, the approval may be renewed/extended.

3.1.4.4 Change in approval conditions

GL shall be informed immediately in writing of any changes in the approval conditions that have a significant influence, such as changes of the production facilities, the production processes, quality control, composition and qualification of the personnel etc. GL shall be notified of any new production procedures in good time before their introduction. GL reserves the right to demand validation tests of such procedures. Serious violations of the approval conditions entitle GL to suspend the approval.

3.2 Quality Management

3.2.1 General

(1) Provided the manufacturer operates and applies a quality management (QM) system in accordance with a recognized standard, and this has been evaluated by GL, a portion of the proofs required in this Guideline may be provided within the context of the QM system. A certification of the QM system by an accredited certification body is recognized through the assessment by GL.

(2) Recognition of the QM system obliges the manufacturer to observe the requirements laid down in this Guideline. The obligation for proof of this rests on the company. GL verifies the effectiveness of the system and the work-specific requirements on the basis of the documentation submitted by the company, e.g. within the context of shop approval, and checks it, at its discretion, by random inspections or by witnessing tests within the QM system.

(3) The manufacturer is responsible for ensuring that all tests and inspections laid down in accordance with this Guideline, as well as with any standards, specifications and other regulations that are also applicable, are carried out.

(4) GL shall be notified without request prior to the introduction of any alterations to the QM system or to production processes which can be expected to have a significant effect on product quality, as listed for example in Section 3.1.4.4. GL reserves the right to check these issues (extraordinary inspection) and to review the approval of the QM system.

(5) Insofar as the certification of the QM system of a certification body was recognized by GL, the manufacturer is under an obligation to inform GL without delay about the loss of the certificate's validity.

3.2.2 Definitions

(1) The definitions of ISO 9000 apply.

(2) Manufacturer is the organizational unit which manufactures a product or independent component of the product, or which assembles and sells a product consisting of subcontracted components.

(3) Quality is the totality of features and characteristics of a product or a service that bear on its ability to satisfy stated or implied needs.

(4) Quality management (QM) comprises all planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

(5) The QM system comprises the organizational structure, responsibilities, procedures, processes and resources for implementing quality management.

(6) The quality audit is a systematic and independent examination to determine whether quality activities and related results comply with planned actions, and whether these actions are implemented efficiently and are suitable to achieve the objectives.

(7) The QM system documentation comprises all the documents describing the functions of the QM system. It consists of:

- QM manual
- QM procedures
- QM work instructions

3.2.3 Requirements for the quality management system

(1) As a minimum, the QM system shall meet the requirements of the QM model according to ISO 9001. ISO 9000 and ISO 9004 contain basic principles and recommendations for the implementation of a QM system.

(2) The QM system shall be worked out in detail in writing (see also Section 3.2.2, para 7).

(3) For the manufacturers of products who do not pursue their own development activities, the exclusion of Subsection 7.3 ("Design and Development") within ISO 9001 is permissible.

3.2.4 Certification of the QM system

(1) A certification of the QM system by a certification body accredited according to EN 45012 is, as a rule, regarded as a prerequisite. The general procedure for the certification is described below.

(2) Certification of the QM system follows completion of the following assessments:

- checking of the QM system documentation in relation to the requirements of ISO 9001
- successful completion of the initial audit by the certification body. This includes a check on whether the QM activities set out in the QM system documentation are being implemented.

(3) The validity of the certificate is maintained by means of regular audits. These audits are carried out at set intervals in time (once a year and, if necessary, more often).

(4) The certification is generally valid for three years. It commences with the date of the certificate. On completion of the re-certification (usually comprising the execution of a renewal audit), a certificate may be issued which again is valid for three years. The validity of the certificate necessitates that all the conditions under which it was granted are still being met and no serious shortcomings have arisen in the QM system.

3.3 Materials

3.3.1 General requirements

3.3.1.1 General

(1) Only suitable materials with guaranteed properties (e.g. strength, toughness – at low temperatures if appropriate, cold deformability, suitability for welding, resistance to rot etc.) may be used for the force- and moment-transmitting components of a wind turbine.

(2) Materials chosen shall be matched to the demands to be made on the component, particularly the type of load (shock load, oscillating load) as well as the external conditions (see Section 4.2) and to the design. The materials chosen shall be named clearly and comprehensively in the documents (drawings, specifications, parts lists) to be submitted for approval.

(3) All materials not listed in this section shall be treated in accordance with the relevant standards as regards quality requirements and test conditions. The special environmental and operational conditions of the wind turbine shall be taken into account.

(4) The temperature range for the materials to be used is laid down in Section 4.2.4. The use of materials outside this temperature range necessitates separate assessment by GL.

(5) For components which are mounted on or installed in wind turbines and with relevance to the Certification, only materials approved by GL may be used in the case of wind turbines for which an application for project certification has been submitted.

(6) Where tests are called for, these are to be performed by the manufacturer if not specified differently in this Guideline. Additional notes on principles and test procedures of metallic materials besides the following can also be taken in dependence on the Guideline of GL (II, Part 1, Chapter 1).

3.3.1.2 Material tests

(1) The type and extent of material testing depends on the importance of and stress on a component, and on the type and extent of the possible or required post-manufacture tests. Depending on the type of certification, design analyses with all the required material and component tests according to Section 1.2.2 (A- and B-Design Assessment), an implementation of the design requirements in construction and erection according to Section 1.2.2.5 (Type Certificate) or surveillance during production according to Section 1.2.3.5 (Project Certificate) are required. If nothing else has been determined in detail, the following requirements apply.

(2) Material test documents (statements of compliance) shall correspond to EN 10204:2005. They shall contain the results of the tests laid down in the standards or additionally agreed or demanded on the basis of the requirements. They shall furthermore contain data on the marking of the materials, so as to permit reliable tracing to components.

(3) Material test documents (statements of compliance) for components of a wind turbine within the scope of the project certificate form a part of the surveillance during production by GL.

(4) Within the scope of the Type Certification IPE (see Section 1.2.2.5), inspection certificates 3.1 in accordance with EN 10204:2005 shall generally be submitted for the materials of those components that are subject to high static or dynamic loads and that are important for the integrity of the wind turbine.

(5) For materials of other components or assemblies that are less highly stressed but of particular importance for the functioning of the wind turbine, test reports 2.2 in accordance with EN 10204:2005 shall be submitted within the scope of the IPE (see Section 1.2.2.5).

(6) Test certificates of redundant or damage-tolerant as well as serial secondary components of the same requirement class can, by way of exception, be certified by test reports 2.2 according to EN 10204:2005.

(7) Especially for welded structures and components made of structural steel categorized in structural members according to Section 3.3.2.1.1, the following material certificates shall during turbine manufacture be taken, stored and submitted to GL within the scope of the IPE (see Section 1.2.2.5):

- 3.2 certificates in accordance with EN 10204:2005 for special structural members
- 3.1 certificates in accordance with EN 10204:2005 for primary structural members
- 2.2 test reports in accordance with EN 10204:2005 for secondary structural members

(8) In cases of doubt, the classification of the materials for components or assemblies shall be agreed with GL. In the case of components not obtained with inspection certificates, the scope of the substitute requirements shall be discussed with GL.

(9) GL reserves the right to extend the scope of surveillance during production accordingly for special materials, production processes or components.

(10) In the case of components not obtained with inspection certificates, the scope of the substitute requirements shall be discussed with GL.

3.3.1.3 Corrosion Protection

3.3.1.3.1 General

Corrosion protection is to be taken into account during the design process of a wind turbine by the selection of suitable materials and appropriate coatings and protective films, plus regular inspection. The assessment of mechanical and electrical components shall take into account not only the integrity but also the influence of corrosion on functioning, e.g. jamming of rusted joints or failure of sensors. In particular, freedom from corrosion is assumed for fatigue calculations. Analogous considerations are to be applied as regards the possibility of erosion, particularly for the rotor blades.

3.3.1.3.2 Scope, application

(1) This section covers corrosion protection of steel and concrete structures. Design, fabrication and installation of the corrosion protection system are subject to approval by GL in connection with the overall certification procedure.

(2) Additional requirements regarding machinery components are given in Chapter 7.

(3) Recognized codes and standards from institutions such as NACE, DIN, BSI, NORSOK, ISO may be used for the design, provided the classification of risk potential is applied in a correct manner.

3.3.1.3.3 Terms, definitions

(1) Anode

An anode is an electrode in a galvanic cell or the part within a corrosion cell which emits a direct current in the form of positively charged ions, usually with anode substance dissipation.

(2) Coating

Coating is a collective term for one or several coherent layers on a base material that are made from non-preformed materials and the binding agents of which are mostly of an organic nature.

(3) Reference electrode

The reference electrode is a half cell characterized by a time-constant potential. In connection with potential values, the reference electrode shall always be indicated.

(4) Cathode

The cathode is the electrode in a galvanic cell or the part within a corrosion cell at which reduction processes occur. Here, electrons leave the metal and/or are consumed by discharging of the positive ions in the electrolyte.

(5) Corrosion

Corrosion is the reaction of metallic material with its environment, which causes a measurable change of the material and may entail corrosion damage.

(6) Corrosion protection

Corrosion damage may be prevented by the following corrosion protection measures:

- by designing the systems and components through the application of suitable structural measures according to EN ISO 12944 Part 3; see Section 3.3.1.3.5
- by influencing the characteristics of the reaction partners and/or modification of the reaction conditions
- by separating the metallic material from the electrolyte through protective layers
- by electrochemical action, e.g. cathodic protection; see IV, Part 2, Chapter 3, Section 3.5.9

(7) Atmospheric zone

The atmospheric zone is the area which is normally dry.

(8) Metallic coating

Metallic coating is a collective term for one or several layers of metals applied on a base material.

3.3.1.3.4 Choice and suitability of corrosion protection systems

(1) For the accessible area within the atmospheric zone, an appropriate coating or a metallic coating according to EN ISO 12944 or an equivalent standard shall be taken.

(2) Void spaces, such as box girders, tube sockets etc., for which proof can be furnished of permanent hermetic sealing do not require internal protection. During assembly, the voids should be clean and dry.

(3) For novel corrosion protection systems that are not yet proven, proof of suitability, e.g. by experiments, will be demanded for the envisaged application.

3.3.1.3.5 Design for corrosion protection

(1) A structural design which takes into account corrosion protection and reduction has a significant effect on the ease of implementing, effectiveness and repairability of the corrosion protection. Basic rules are addressed in e.g. EN ISO 12944 Parts 3 and 5.

(2) Surfaces at risk from corrosion should be designed to be as smooth as possible. Any necessary stiffenings, fittings, pipes etc. shall wherever possible be located in low-corrosion regions. Inaccessible hollow components shall be welded tight.

(3) Areas in which water or aggressive media can accumulate (water pockets) shall be avoided by means of suitable measures such as slopes, passages or run-offs. Condensation shall be reduced by means of design measures such as ventilation.

(4) Residues from welding, such as slag, loosely attached splashes and beads, shall be removed. Splashes or beads melted onto the surface shall be removed if the corrosion stress or the coating system makes this necessary.

(5) If the coating system, the stress in the structure or accident prevention requires it, burrs shall be removed and sharp edges rounded off.

3.3.1.3.6 Material selection

For areas which cannot be protected by coatings and protective coverings, suitable materials shall be used. The corrodibility of various materials is described in DIN 50930.

3.3.1.3.7 Coatings

(1) Coatings can be selected in accordance with EN ISO 12944 Part 5, which lists the stressing, and the coating system to be used. Additional information can be taken from the GL Rules for Classification and Construction, Offshore Technology, Edition 1999, Chapter 2, Section 6, and the Shipbuilding Association Guideline (Schiffbautechnische Gesellschaft) STG Guideline No. 2215.

(2) For coating systems, different guidelines and standards may have to be applied after consulting with GL.

(3) Surfaces to be protected by coating shall be designed to be accessible for the necessary activities such as surface preparation, application, inspection and maintenance. Surface preparation shall be effected in accordance with EN ISO 12944 or an equivalent standard.

(4) For all coating systems that are not conform to any recognized standard, it is possible to apply to GL for an approval. It is necessary to provide sufficient evidence to GL that the coating material is suitable for the intended purpose. A written application must be submitted to GL. After successful examination of the product data sheet, coating specifications and suitability documentation appended to the application, e.g. references and relevant test results etc., a certificate is issued by GL.

(5) Proof of efficiency of coating materials shall be furnished either by many years' proven practical use under the expected conditions or by well-founded experimental results.

(6) The choice of materials, coating thicknesses, workmanship, testing etc. shall comply with EN ISO 12944 or an equivalent standard.

(7) Coatings shall be sufficiently resistant to the respective corrosion medium under the given service conditions.

(8) Coatings shall be as resistant as possible to damage due to fouling.

(9) The coatings in the atmospheric zone shall be inspected on the occasion of the usual periodical surveys of the structure, according to an agreed inspection plan, and any damage shall be repaired.

3.3.1.3.8 Metallic coatings and platings

(1) Metallic coatings may have a more positive or a more negative free corrosion potential than the base material, which in general is unalloyed or low alloyed steel. They should be free from cracks and pores.

(2) With coatings using materials having a more positive potential (e.g. nickel- and copper-based alloys, stainless steel), there is a risk of bi-metallic corrosion at pores in the coatings and at the transition to the base material. Therefore, the coatings shall be free from cracks and pores. The transitions to the base material shall be coated.

(3) Coatings made of materials with a more negative potential, e.g. zinc or aluminium alloys, are well suited for temporary protection of equipment in the atmospheric zone.

(4) In the surface preparation and application and testing of the metallic coatings, EN ISO 12944 or equivalent standards shall be observed.

(5) The plating of steels shall show perfect bonding with the base material, proof of which may be furnished by ultrasonic testing.

(6) In the case of metallic coatings or platings, attention shall be paid to damages due to mechanical effects or bi-metallic corrosion. Damage shall be repaired in agreement with GL.

3.3.1.3.9 Reinforced concrete

(1) The cover of the concrete above the reinforcement that will be applied should have the minimum value according to DIN 1045-1:2001-07. The corrosion protection system of prestressing, tendons and their fixing shall be designed in consultation with GL.

(2) Bonded tendons for prestressing concrete have to be protected against corrosion according to EN 445 – 447, EN 523 and EN 524. The behaviour and the quality control of the steel strip sheaths for prestressing tendons are discussed in EN 523 and 524.

3.3.2 Metallic materials

(1) Only suitable materials with guaranteed properties (e.g. strength, toughness – at low temperatures if appropriate, cold deformability, suitability for welding etc.), as mentioned in the next section, may be used for the force- and moment-transmitting components of a wind turbine made of metallic materials. The use of materials according to other regulations or standards requires the consent of GL.

Note:

Metallic materials are generally differentiated into ductile (e.g. S235 J2+N), semi-ductile (e.g. EN-GJS-400-18U-LT) and non-ductile (e.g. EN-GJS-700-2U) materials.

(2) The material tests shall be performed in accordance with Section 3.3.1.2.

(3) For the machinery components such as gearing, bearings, brakes, couplings etc., materials suitable for these components shall be used. Quality requirements and test conditions shall be taken from the relevant standards, taking into account the environmental operational conditions (see Section 4.2). Further special requirements are listed in Chapters 6 and 7.

(4) In special cases, limited continued operation of the wind turbine may be accepted by GL in the event of an incipient crack that is growing steadily. The material data to be applied for determining the remaining lifetime of a component shall be agreed with GL before use.

(5) The actual material qualities of the component shall be taken into account in fatigue verification by using related upgrading factors for S/N curves in accordance with the specified quality (e.g. j and j0, see Section 5.3.3.5.3). If the quality is defined differently in specific areas of the component, it shall be assured that areas of different quality are covered by the analysis.

3.3.2.1 Structural steels

(1) For the structures and components in accordance with Chapters 6 and 7, structural steels according to EN 10025-2 as well as weldable fine-grained steels according to EN 10025-3 may be used. With the consent of GL, other equivalent structural steels may also be used. The characteristic values shall be taken from the corresponding standards. The demands made on special steels are laid down by GL individually for each case. For hollow sections, the standards EN 10219-1 (cold-formed, welded) and EN 10210-1 (hot-finished) apply.

(2) The structural steels used for less important, non-load-bearing parts shall have sufficient strength and shall exhibit the properties required for the particular application (e.g. cold-workability, weldability). Welded joints between these steels and those of the load-bearing structures and components shall not adversely affect the components.

(3) Steels with improved through-thickness properties shall be employed where structural members are rigid and/or particularly thick and where high residual welding stresses are to be expected, e.g. due to large-volume single-bevel butt joints or double-bevel butt joints with full root penetration, simultaneously implying high stresses acting in the through-thickness direction of the materials. This will normally be the case where special structural members are concerned.

(4) If properties are to be proved in the through-thickness direction, the testing shall be carried out in the final heat treatment condition. Testing is not required for a product thickness below 25 mm. The required quality class may be calculated in accordance to EN 1993-1-10; the test shall be performed on the basis of an appropriate standard, e.g. EN 10164.

(5) Regarding their internal defects (flaws), plates and wide flats for which through-thickness property requirements exist shall at least meet the requirements as listed in the relevant standards, e.g. EN 10160 and quality class S2/E2 or equivalent. All flange sheet metals of the tower flange connection shall be tested additionally with respect to being layer-free by means of ultrasonic testing.

3.3.2.1.1 Member categories for welded structures

(1) In the choice of materials for the different members of the steel structure, the criteria explained below shall be observed:

- importance of the member within the structure (consequence of failure, redundancy)
- character of load and stress level (static or dynamic loads, residual stresses, stress concentrations, direction of stresses in relation to the rolling direction of the material etc.)
- design temperature
- chemical composition (suitability for welding)
- yield and tensile strength of the material (dimensioning criteria)
- ductility of the material (resistance to brittle fracture at the given design temperature)
- through-thickness properties (resistance to lamellar tearing)

Additional properties, such as corrosion resistance, shall be considered where applicable.

(2) Depending on the importance of the structural member and on the type of load and the stress level, a structure can be subdivided into the following component categories:

(3) Special structural members

These are members essential to the overall integrity of the structure and which, apart from a high calculated stress level, are exposed to particularly arduous conditions (e.g. stress concentrations or multi-axial stresses due to the geometrical shape of the structural member and/or weld connections, or stresses acting in the through-thickness direction due to large-volume weld connections on the plate surface).

Note:

This applies to e.g. ring flanges of tubular towers, and thick-walled points of introduction or reversal of forces.

(4) Primary structural members

These are members participating in the overall integrity of the structure or which are important for operational safety and exposed to calculated load stresses comparable to the special structural members, but not to additional straining as mentioned above.

Note:

These are e.g. tower shells of onshore wind turbines, main frame and generator carrier

(5) Secondary structural members

These are all structural members of minor significance, exposed to minor stresses only, and not falling under the above categories of “special” and “primary”.

Note:

These are e.g. non-structural walls, stairs, pedestals, mountings for cables etc.

(6) The categories of structural members as per Section 3.3.2.1.1, para 2, shall be fixed in the design stage and indicated in the design documentation.

3.3.2.2 Cast steel

(1) For the structures and components in accordance with Chapters 6 and 7, cast steels of the grades GE200, GE240 and GE300 according to EN 10293 as well as GP240GH+QT, GP280GH+QT,G17Mn5, G20Mn5+N and G20Mn5+QT according to EN 10213-2 and EN 10213-3 may be used. Cast steel grades according to other specifications or standards may also be used with the consent of GL, provided they are equivalent to the grades listed above as regards their mechanical properties and, if appropriate, weldability and also provided that proof has been furnished of their suitability for the intended application. For this purpose, a once-only suitability test may be required.

(2) Unless agreed otherwise, the quality requirements and test conditions in accordance with the above-mentioned standards apply to steel castings. Furthermore, the provisions set out in EN 1559-1:1997 and EN 1559-2:2000 shall be observed. The Charpy impact energy shall be verified at a temperature corresponding to the minimum design temperature (cf. Section 3.3.1.1, para 4).

(3) The conditions listed below shall also be observed:

- In the case of steel castings to be used in welded designs, the carbon content of the above-mentioned grades shall not exceed 0.23 %, and the sum of chromium and molybdenum content 0.30 %. The composition of each melt shall be certified by the manufacturer.

- The steel castings shall be supplied either normalized or hardened and tempered, depending on the type of cast.
- For cast components that are predominantly dynamically stressed, quality level 3 in conjunction with EN 12681:2003 or ISO 4993:2009 (Radiographic test), EN 12680-2:2003 or ISO 4992-2:2006 (Ultrasonic test), EN 1371-1:1997 (Dye penetration test) and EN 1369:1997 (Magnetic crack detection test) is the minimum permitted. The quality levels shall correspond to the assumptions of the computational analyses as per Section 5.3.3.5.3.
- Steel castings may not exhibit any faults which might adversely affect their use and appropriate processing.
- The removal of faults through fabrication welding or repair welding is permissible only with specifications approved by GL. The qualification of the welding workshop and the welder performing the work shall be verified in accordance with Section 3.4.2.

3.3.2.3 Stainless steels

(1) Stainless steels shall be selected with respect to their resistance to corrosion, taking into account the processing conditions (e.g. welding). If nothing else has been agreed for individual cases, suitable steels, e.g. according to EN 10088 (Stainless steels) and EN 10213-4 (Steel castings for pressure vessels) may be selected in the case that no delivery is to take place on the basis of a specification approved by GL.

(2) Only those grades suitable for welding with guaranteed resistance to intercrystalline corrosion may be used for welded structures. If it is intended to weld castings without post-weld heat treatment, only grades of cast steel that are corrosion-resistant in this condition as well shall be used, e.g. cast steels stabilized with Nb or containing not more than 0.03 % C.

(3) Other grades of cast steel conforming to other standards or material specifications may be used, provided that they are comparable to the grades of cast steel described in EN 10213-4 with regard to their delivery condition, heat treatment, chemical composition, mechanical properties and weldability, and provided that proof has been furnished of their suitability for the intended application. For this purpose, a first-time suitability test may be required.

(4) The limits for the lowest design temperatures according to Section 3.3.1.1, para 4 shall be observed.

3.3.2.4 Forging steels

This part contains requirements to be applied in the manufacture and testing of forgings. Additional notes on selecting suitable materials can also be taken from the Guideline of GL (II, Part 1, Chapter 2, Section 3 [3.3]).

3.3.2.4.1 Selection of steel and Standards

Forgings and bar stock for structures and components as per Chapters 6 and 7 shall be suitable for their application and shall satisfy the minimum requirements specified. The steels shall be identified by the standardized designations and be selected to EN 10083 in accordance with the requirements; in the case of larger cross-sections (i.e. greater than 100 mm / 250 mm; see EN 10083) according to Stahl-Eisen-Werkstoffblatt (Steel/Iron Materials Data Sheet) SEW 550 or EN 10250 Part 1-3. Further notes on selecting suitable materials can also be taken from the Guideline of GL (II, Part 1, Chapter 2, Section 3 [3.3]). For tempering and case-hardening steels, e.g. for the manufacture of gearwheels and pinions, the standards EN 10083 and 10084 apply; for stainless steels EN 10088 applies. Forgings and bar stock in accordance with other standards or manufacturers' material specifications may be used if properties equivalent to those in the standards listed above can be guaranteed, and if proof has been furnished of their suitability for the intended application. For this purpose, a first-time suitability test may be required.

3.3.2.4.2 Production processes

(1) Forging steel shall be produced by a basic oxygen steel-making process in an electric furnace or by other processes approved by GL and shall be killed. On request, GL shall be informed of the steel-making process used. A sufficient amount of material shall be cropped from the top and bottom ends of ingots to ensure that the forgings are free from any harmful segregations. This term includes all inhomogeneities liable to impair the required characteristics.

(2) Given a reasonable machining allowance, workpieces shall as far as possible be forged to the final dimensions. Excessive machining to give the forging its final shape which may impair its characteristics, e.g. by laying open the core zone, is not allowed. Necks of shafts, pinions and journals exceeding 1/10 of the outer diameter shall be produced as far as possible by stepped forging. The degree of deformation shall be such that the core zone of the forging undergoes sufficient plastic deformation.

(3) Unless otherwise approved, the total reduction ratio shall be at least:

- for forgings made from ingots or from forged blooms or billets, 3 : 1 where L > D and 1.5 : 1 where L < D
- for forgings made from rolled products, 4 : 1 where L > D and 2 : 1 where L < D
- for forgings made by upsetting, the length after upsetting is to be not more than one-third of the length before upsetting or, in the case of an initial forging reduction of at least 1.5 : 1, not more than one-half of the length before upsetting
- for rolled bars, 6 : 1.

L and D are the length and diameter respectively of the part of the forging under consideration. Annular and hollow shapes shall be produced from sections cut from the ingot or bloom which have been suitably punched, drilled or trepanned before the parts are rolled or expanded over a suitable mandrel.

3.3.2.4.3 Heat Treatment

(1) All forgings shall be heat treated in a manner appropriate to the material. The treatment shall be carried out in suitable furnaces, maintained effectively and regularly. These shall be equipped with means for controlling and indicating the temperature. The dimensions of the furnace shall make it possible to bring the entire forging uniformly to the required annealing temperature. Where, in the case of very large forgings, the furnace dimensions do not permit total normalizing in one step, alternative heat treatment processes shall be agreed with GL.

(2) All hot-forging work shall be completed before the final heat treatment. If a forging has for any reason to be reheated for further hot working, the final heat treatment shall be repeated.

(3) If a forging is hot- or cold-straightened after final heat treatment, subsequent stress-relieving to remove the residual stress may be demanded.

(4) Forgings which after forging undergo large changes in cross-section by machining may be hardened and tempered only after adequate pretreatment. The weight at hardening and tempering shall not be more than 1.25 times the finished weight.

3.3.2.4.4 General forging quality

(1) All forgings shall be free from any faults which may impair use and processing to more than an insignificant extent, e.g. flakes, cracks, shrinkage holes, segregations, peripheral blowholes and major non-metallic inclusions. Forgings to be delivered unmachined shall have a smooth surface appropriate to the production process.

(2) Small surface faults may be removed by pointing and/or grinding. Complete removal of the fault shall be demonstrated by a magnetic crack detection test or a dye penetration test.

(3) The removal of defects by welding is permissible only in exceptional cases with the agreement of GL if the defects are of limited extent and occur at points which are subject to low operating loads. The removal of faults through fabrication welding or repair welding is only permissible with approved procedure testing. With regard to the qualification of the welding workshop and the welder performing the work, Section 3.4.2 shall be observed. Prior to the start of welding work of this type, the welding process, the heat treatment and the scope of the tests shall be agreed with GL.

3.3.2.4.5 General requirements for the material

Within the scope of the IPE (see Section 1.2.2.5), certificates of the following inspections and tests shall be submitted for those components that are subject to high static and dynamic loads and that are important for the integrity of the wind turbine.

(1) Chemical composition

The manufacturer shall determine the chemical composition of every melt and submit a corresponding certificate. This certificate shall state the chemical composition of the melt which characterizes the steel grade. If there is any doubt as to the composition, or if the connection between certificate and forging cannot be proved, a product analysis shall be carried out.

(2) Mechanical testing

Tensile test:

The mechanical properties shall be ascertained by tensile test to determine tensile strength (Rm), upper yield strength (upper yield point) (ReH) or 0.2 % proof stress (Rp0.2), elongation (A) and reduction in area (Z).

Charpy impact testing:

A Charpy impact test shall be carried out if this is stated in the standards. Unless otherwise specified, the Charpy impact energy shall be verified on every forging or test piece by Charpy impact tests.

Sampling:

As a rule, the taking of samples from forgings shall be effected by forging-on sample sections outside the forging dimensions. The position, shape and size of the samples shall be chosen to achieve forming ratios and cooling rates similar to those in the dynamically highly stressed regions of the component. The sample section may generally be separated from the forging only after the final heat treatment. Subsequent stress relieving need not be taken into account in this connection. Premature separation is permitted only if unavoidable for production reasons. In this event, the forging and the sample section shall be heat treated together.

In deviation from this provision, in the case of series-production drop forgings, the samples may be taken from items surplus to requirements or separately forged sample sections; these shall belong to the same melt and be heat treated together with the associated items under test. The test batch sizes laid down in the standards apply as regards sample selection.

All sample cut-offs shall be forged with the same degree of deformation to that cross-section which is also representative of the forging's typical cross-section. The sample cut-offs shall be large enough to provide specimens for any test which might be necessary as well as those required for any repeated tests.

All test sections and samples shall be so marked that they can be clearly related to the forgings or test batches which they represent.

The test specimens may be taken from the samples in the longitudinal, tangential or transverse direction in relation to the fibre pattern.

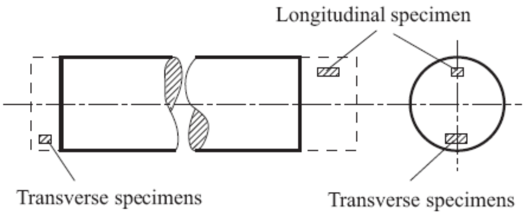

Fig. 3.3.1 Position of specimens

The location of the test specimens in the cross section of the heat-treated region shall be as follows:

The specimens shall be taken starting from the surface at a distance of 1/4 of the diameter or the (wall) thickness, but max. 80 mm, and at a corresponding distance from a further, adjacent surface.

Non-destructive testing

Where non-destructive tests are called for, these shall be performed by the manufacturer and/or finishing plant.

If surface crack testing is required, it shall preferably be effected by means of the magnetic crack detection method, except in the case of austenitic steels. The tests shall generally be carried out on forgings which have undergone final heat treatment, if possible after machining. If current flow is being used, care shall be taken that no penetration points are caused by the contact electrodes. The effective tangential field intensity shall be at least 2 kA/m (25 Oe) at the workpiece surface, but shall not exceed 5 kA/m (62.5 Oe).

Surface crack tests using the dye penetration method are possible in exceptional cases (and for austenitic steels). The tests shall be carried out with a testing-medium combination comprising penetrant, intermediate cleanser and developer in accordance with the testing-medium manufacturer's instructions. A surface crack test by the dye penetration method shall be performed prior to any sandblasting or shot peening processing of the component.

For ultrasonic testing, the general principles of EN 583 shall be applied. Ultrasonic testing shall preferably be carried out while the component still has a simple geometric shape, the components to be tested having been at least normalized. Provided it is permitted by shape and size of the component, ultrasound shall be passed through it radially and axially. Technical data relating to the test, such as method, type of appliance, testing head, appliance adjustment, recording threshold and error margins shall be laid down and made known by the manufacturer according to EN 583-1:1998. The qualification of the tester shall be demonstrated according to EN 473:2008-09. The company shall prepare a report on the ultrasonic testing according to EN 583-1:1998 containing the assessment of the readings.

Requirements for surface finish and dimensions

The manufacturer shall inspect each forging for surface finish and compliance with the dimensional and geometrical tolerances. The surface of the forgings shall be clean and properly prepared for inspection, and surface defects shall be removed. This condition shall be achieved wherever necessary, unless the parts are to be submitted in the rough-machined condition

3.3.2.5 Cast iron

(1) For structures and components in accordance with Chapters 6 and 7, cast iron with spheroidal graphite (EN-GJS) according to EN 1563:2005 may be used, depending on the mechanical properties required. Furthermore, the provisions set out in EN 1559-1:1997 and EN 1559-3:1997 shall be observed.

(2) Without additional verification, cast iron with a fracture elongation ≤ 12.5 % (base thickness) shall not be selected for components that play a significant role in the transmission of power and are under high dynamic stress, e.g. rotor hubs, gearbox housings with integrated rotor bearings, main bearing housing and machine foundations.

(3) The Charpy impact energy shall be verified at a temperature corresponding to the minimum design temperature (cf. Section 3.3.1.1, para 4). If Charpy impact testing at the minimum design temperature is not applicable for a chosen material, an alternative evaluation procedure to verify the suitability of the material at the minimum design temperature shall be agreed with GL.

(4) For the determination of the microstructure, ISO 945-1:2009 shall be applied. The manufacturing process of cast iron with spheroidal graphite shall ensure that 90 % of the graphite has been segregated in the spheroidal form V and VI and in the spheroidal size between 3 and 7 (according to ISO 945-1:2009). For the ferritic types, the pearlite proportion within the grain structure of the metallic base material shall not exceed 10 % (following ISO 1083:2004).

(5) The use of other types of cast iron according to other standards or material specifications shall be agreed with GL.

(6) For the assessment of the casting quality of components with consideration of internal flaws, non-destructive testing methods such as ultrasound (according to EN 12680-3:2003) and/or radiographic tests (according to EN 12681:2003 or ISO 4993:2009) shall be applied. For radiographic tests, the radiation source shall be selected in relation to the maximum wall thicknesses in accordance with EN 444. If no satisfactory rear-panel or error echo is obtained for the ultrasonic test, a combination with the radiographic test shall be performed.

(7) For components that are predominantly dynamically stressed and made of cast iron with spheroidal graphite, a quality level requirement shall be set according to EN 12680-3:2003 (Ultrasonic test) and VDG instruction sheet P-541 (Verein Deutscher Giessereifachleute) in conjunction with EN 12681:2003 or ISO 4993:2009 (Radiographic test), EN 1369:1997 (Magnetic crack detection test) and EN 1371-1:1997 (Dye penetration test). These shall correspond to the assumptions of the computational analyses as per Section 5.3.3.5.3.

(8) The flaw types blowholes (flaw class A), non-metallic inclusions (B) and enclosed shrinkage holes (C) shall be classified according to their quality after the radiographic test (see also Table 3.3.1). Here the worst acceptable is quality level 3 according to VDG instruction sheet P-541. Dross (Z) or shrinkage holes (C) cut by mechanical processing are fundamentally inadmissible in highly stressed areas and shall be removed by mechanical means, taking into account the permissible reduction in wall thickness. All other types of flaws shall, if applicable, be assessed separately and possible countermeasures shall be coordinated with GL.

Table 3.3.1 Allocation of the flaw class to wall thicknesses and quality levels for radiographic testing of EN-GJS on the basis of VDG instruction sheet P-541

Quality level	Flaw classes		
	Wall thickness up to 100 mm	Wall thickness > 100 – 250 mm	Wall thickness > 250 – 400 mm
1	A1, B1, C1	A1, B1, C2	A1, B1, C3
2	A2, B2, C2	A2, B2, C3	A3, B3, C4
3	A3, B3, C4	A3, B3, C5	A3, B3, C6

(9) For components that are predominantly dynamically stressed and made of cast iron with spheroidal graphite, a quality level requirement shall be set according to EN 12680-3:2003 for indications to be reported. Here the worst acceptable is quality level 3.

(10) For the flaws which are near to the surface of components predominantly under dynamic stress, a quality level requirement shall be set according to EN 1369:1997 (Magnetic crack detection test) or EN 1371-1:1997 (Dye penetration test) for indications to be reported. Here the worst acceptable is quality level 3.

(11) The removal of sample cut-offs or test specimens for determining the mechanical properties and the grain and graphite structures, and for determining the casting quality, shall be so executed that the typical characteristics of the component are registered properly, especially in the highly stressed areas of the component. In many cases, it is necessary to prescribe varying sampling points on the component.

(12) All sample cut-offs and test specimens shall be so marked that they can be clearly assigned. The corresponding specifications shall be submitted to GL.

(13) The test results shall be documented in accordance with Section 3.3.1.2.

(14) The removal of faults through fabrication welding or repair welding is permissible only with approved procedure testing, e.g. approved welding procedure specifications (WPS) and welding procedure approval record (WPAR). With regard to the qualification of the welding workshop and the welder performing the work, Section 3.4.2 shall be observed. Prior to the start of welding work of this type, the welding process, the heat treatment and the scope of the tests shall be agreed with GL. GL shall be involved at a very early stage of the process.

(15) Mixed welding of dynamically stressed components is inadmissible.

(16) The limits for the lowest design temperatures according to Section 3.3.1.1, para 4 shall be observed.

3.3.2.6 Aluminium alloys

(1) Only aluminium alloys that are suited to the intended purpose and have been approved by GL shall be used. If applicable, proof of suitability for welding shall be furnished for the alloys.

(2) As regards fatigue strength and sensitivity to notches, aluminium is comparable to high tensile steels, and therefore demands careful design and manufacturing.

(3) Proper processing and suitable corrosion protection shall be applied in order to prevent contact corrosion and particularly corrosion in a marine atmosphere.

3.3.2.6.1 Wrought alloys

(1) For the chemical composition of the aluminium alloys, the Euronorm EN 573 shall be observed, for the mechanical properties EN 755-2, and for the definition of the material conditions of semifinished products EN 515.

(2) Compliance with the tolerances and the requirements for the general condition lies within the responsibility of the manufacturer.

3.3.2.6.2 Cast alloys

(1) The chemical composition and mechanical properties of castings made of aluminium and aluminium alloys shall comply with the values given in Euronorm EN 1706.

(2) All castings shall be free from any internal or external faults which may impair use and competent processing to more than an insignificant extent.

(3) If defects are to be removed by welding, the manufacturer shall compile a welding specification and obtain the consent of GL. Furthermore, in the case of doubts concerning the freedom from defects of the castings, non-destructive tests shall be initiated by the casting manufacturer and performed at the relevant points. Repaired defects as well as areas that are critical from the viewpoint of casting technology shall be included in the tests.

(4) The results of the tests shall be documented in accordance with Section 3.3.1.2.

3.3.3 Fibre reinforced plastics (FRP)

3.3.3.1 Definitions

(1) Fibre-reinforced plastics are heterogeneous materials, consisting of a cured reaction resin compound as matrix with fibrous reinforcing materials embedded in it.

(2) The reaction resin compound is a multiple-component mix, consisting of reaction resin and hardener, plus possibly additives.

(3) Reinforcing materials are fibres of various materials processed to form various reinforcement products, depending on the intended use. A distinction is made between:

– homogeneous:	The reinforcement product contains fibres of one single material.
– inhomogeneous:	The reinforcement product contains fibres of diverse materials, though individual layers or directions in one layer may be homogeneous.

(3) Laminate is produced by layerwise arrangement of reinforcement products with reaction resin compounds.

(4) Sandwich laminate comprises one or multiple cores consisting of a low-density material in addition to the layers of reinforcement material.

(5) Prepreg is a reinforcing material pre-impregnated with reaction resin compound, and can be worked without having any more resin compound added.

3.3.3.2 General

(1) The properties of fibre-reinforced plastics are strongly influenced by their processing. For this reason, the requirements for manufacturers set out in Section 3.4.3 shall be observed.

(2) Notwithstanding the availability of approvals or confirmations of the quality of individual components (resin compound, reinforcing material, adhesive etc.), it shall be checked that the properties of the corresponding composite material comply with the design values.

3.3.3.3 Reaction resin compounds

(1) Depending on the purpose and thus on the requirements, a distinction shall be made between laminating resins and gelcoat resins. For the combination of gelcoat and laminating resins, compatibility shall be demonstrated unless the basic resins are the same.

(2) Gelcoat resins are intended to protect the laminate durably against external damage and influences. In cured condition, they are therefore required to have good resistance to moisture, chemical attack, UV radiation, marine and industrial environments, and to exhibit a high degree of resistance to abrasion and a low water absorption capacity as well as a high elasticity. The only additives permitted are, to a limited extent, thixotropic agents and pigments.

(3) Laminating resins shall have good impregnation and wetting properties in the working state, whereas in the cured state they shall be moisture-resistant and highly resistant to ageing. These properties shall also be provided with the permitted additives and fillers.

(4) In the case of reaction resin compounds, all additives to resins (catalysts, accelerators, inhibitors, fillers and pigments) shall be harmonized with the reaction resin and be compatible amongst themselves and with it, whereby total curing of the resin shall be guaranteed. The additives shall be dispersed in the resin compound with care and in accordance with the manufacturer's instructions. Catalysts which initiate the hardening process and accelerators or inhibitors which control the working time (pot life) and curing time shall be used in accordance with the manufacturer's processing guidelines.

(5) In the case of epoxy resins, the resin and hardener constituents shall be mixed exactly to the manufacturer's regulations. As a rule, only the resin/hardener combinations prescribed by the manufacturer are permissible.

(6) All systems which are cured at room temperature (cold-curing systems) shall be matched in such a way that satisfactory curing is guaranteed at temperatures from 16 °C to 30 °C. Cold-curing systems intended to cure at other temperatures and hot-curing systems may only be used in accordance with a production specification approved by GL.

(7) Fillers shall not significantly impair the properties of the resins. The type and amount of filler may not lead to the resin properties seriously dropping below the nominal properties. In general, the proportion of fillers in the laminating resins shall not exceed 12 % by weight (including a maximum of 1.5 % by weight of thixotropic agent). If the manufacturer has laid down a lower figure, however, this shall apply. The proportion of thixotropic agent in the gelcoat resin may not exceed 3 % by weight.

(8) Pigments shall be weatherproof and consist of inorganic or light-resistant organic colouring substances. Their maximum permitted proportion shall not exceed the figure laid down by the manufacturer but not more than 5 % by weight.

3.3.3.4 Reinforcing materials

(1) Commonly used reinforcing materials with continuous filaments of glass, carbon fibre and aramide are available in various forms:

- Rovings: A large number of roughly parallel fibres bundled together, twisted or untwisted. In spray moulding processes, they can be used as cut rovings.
- Mat: Random layering of continuous filaments or strands of fibres at least 50 mm long, bonded together by means of a binder.
- Fabric: Fibre strands woven together, the conventional weave types for textiles such as linen, satin, twill or sateen being employed. Warp and weft may differ as regards material and/or thread count.
- Complex of fibres: Unidirectional layers of fibres randomly arranged one above the other, and either glued or tacked to one another or to mats by thin fibre strands. There may be differing materials and/or thread counts in the individual layers.

(2) The fibres shall be given protective and/or adhesion-improving coatings (in the case of glass fibres “size”, in the case of carbon fibres “finish”, in that of aramide fibres “avivage”), matched to the intended laminate resin. This is necessary to ensure an adequate ageing- and moisture-resistant bond between the fibres and laminating resin.

(3) For glass fibres, aluminium-boron-silicate glass (alkaline-oxide content < 1 %) shall preferably be used, for instance E-glass in accordance with VDE 0334/Part 1 – Section 4. Other types of glass, such as R- or S-glass, may also be permitted by GL if suitable.

(4) For glass fibre products, no further proof is needed if the average filament diameter of the glass fibres does not exceed 19 µm (see Section 5.5.4, para 13).

(5) In the case of carbon fibres, pitch-based and “heavy tow” products are not permissible without further proof.

Note:

Heavy tow fibres are carbon fibres with a filament count of 48 K to 320 K, exhibiting a carbonization grade less than 99 %.

3.3.3.5 Core materials

(1) Core materials shall be proved to be suitable for the intended purpose and shall not impair the curing of the laminating resin compound. Especially for rigid plastic foam, the permissible material temperature may not be exceeded when curing the laminating resin.

(2) Core materials other than those listed below may be used with the consent of GL, provided they are suitable for the intended purpose.

(3) Rigid plastic foam used as core material for sandwich laminates or as reinforcing webs shall have a closed-cell structure and shall be highly resistant to the laminating resin and the adhesive, as well as to ageing and to marine and industrial environments. Other requirements are a low water absorption capacity and a sufficient raw density.

(4) End-grain balsa intended for use as core material for sandwich laminates shall meet the requirements below. It shall

- be treated with fungicide and insecticide immediately after felling,
- be sterilized and homogenized,
- be kiln-dried within ten days of felling,
- have an average moisture content of 12 %.

Due to the possible water absorption of the end-grain balsa, it shall be completely sealed in the component.

3.3.3.6 Prepregs

(1) Fibre reinforcement pre-impregnated with laminating resin compound (prepregs) shall meet the demands on its constituent parts. Furthermore, the resin content shall not be less than 35 % by volume, and there shall be adequate adhesiveness at working temperature.

(2) For prepregs, the storage conditions and the shelf life shall be specified on the packaging. Prepregs shall no longer be used once the expiry date set by the manufacturer has passed, unless their suitability for further use has been verified by appropriate tests.

(3) For reinforcement materials with intermediate layers of reaction resin, similar requirements apply.

3.3.3.7 Adhesives

(1) Two-component reaction adhesives shall preferably be used, if possible based on the laminate resin compound.

(2) Where hot-curing adhesives are used, the maximum permissible thermal stress on the materials to be bonded may not be exceeded. The same applies for single-component hot-melting adhesives.

(3) The adhesives shall be used in accordance with the manufacturer’s instructions. They shall not affect the materials to be bonded and shall have a good resistance to moisture and ageing. The effect of temperature on the strength of the adhesive bond should be as low as possible.

(4) The adhesives shall be suitable for the operating temperature of the corresponding component (see Section 5.5.2.2, para 4, and Section 5.5.4, para 8).

3.3.3.8 Approval of materials

(1) If FRP components for which surveillance of production has been requested are manufactured, then prior approval by GL is required for all materials used. The approval conditions are specified in [3.1]. Approval by other authorities may be accepted after agreement with GL, provided the scope of the tests on which the approval is based meets the requirements.

(2) Before manufacture of the components, the necessary material approvals shall be submitted in the above case. If none or not all of the necessary approvals are available, proof of the properties of the base materials may in exceptional cases, and with the agreement of GL, be obtained in the context of the material tests required for the laminates of the component.

3.3.4 Wood

3.3.4.1 Types of wood

Quality level I pine wood of class S 13 according to DIN 4074 and quality level I according to DIN 1052 or wood with equivalent strength properties shall be used, with a laminar thickness after planing which does not exceed 33 mm. For solid wood rotor blades, the board width shall not exceed 22 cm.

3.3.4.2 Material testing and approval

(1) All glue and coating components and all wood preservatives used in the manufacture of wooden rotor blades shall be approved in advance by GL. Approval shall be applied for from GL by the material manufacturer or supplier.

(2) Approval will be granted if testing under the surveillance of GL or a report from an independent testing body recognized by GL proves that the material meets all the requirements of GL.

(3) The proofs shall be submitted before production commences.

3.3.4.3 Glues and adhesives

(1) Glues and adhesives used in the manufacture of wooden rotor blades shall be compatible with the wood constituents, wood preservatives and coating materials. They shall be resistant to ageing and fatigue in the face of sharp climatic variations.

(2) Only resorcinol resin glues or epoxy resins shall be used. These shall have passed the test in accordance with DIN 68141.

(3) Synthetic resin glues and adhesives, their constituents plus coating materials shall no longer be used once the expiry date set by the manufacturer has passed, except with the consent of the manufacturer and GL.

3.3.4.4 Surface protection

The surface protection shall ensure effective protection against moisture. The materials used shall exhibit high elasticity, shall be impermeable to water and shall have little tendency to absorb steam. They shall have good resistance to UV radiation and ageing and to marine, tropical and industrial environments. Furthermore, adequate resistance to abrasion shall be guaranteed. Compatibility with the wood constituents and preservatives shall be ensured. Fabric inserts may be used to prevent cracking.

3.3.4.5 Wood preservatives

Before use, wood preservatives shall have been proved to be compatible with glues and adhesives in accordance with DIN 52179. In addition, compatibility with the surface-protection materials shall be ensured.

3.3.4.6 Mechanical fasteners

Fasteners securing the wooden blades to the rotor hub shall be made from materials which guarantee long-term operation. If metal components are used, the design shall be such that it takes into account the great differences in stress and strain behaviour between these components and wood.

3.3.5 Reinforced concrete and prestressed concrete

3.3.5.1 General

(1) The sub-sections below apply to site-mixed concrete, ready-mixed concrete and factory-made concrete.

(2) They refer to the load-bearing and bracing components of non-reinforced, reinforced and prestressed concrete with a close-grained texture.

3.3.5.2 Standards

(1) Recognized international or national standards relating to concrete structures shall be used as a basis for design, calculations, construction, production and execution.

(2) The following standards are recognized for design and calculations:

- EN 1992 (Eurocode 2): Design of concrete structures
- DIN 1045-1: Concrete, reinforced and prestressed concrete structures – part 1: Design and construction
- For fatigue verification: CEB FIP Model Code 1990

(3) If other standards or methodologies are used for the design and the calculations of the concrete structures, they shall fulfil at least the safety level of the above-mentioned standards. If not, the safety of the proposed design and calculation methodology shall be demonstrated and shall be agreed with GL.

(4) The following standards are recognized for production and construction:

- EN 206: Concrete
- DIN 1045-2: Concrete, reinforced and prestressed concrete structures – part 2: Specification, properties, production and conformity
- EN 10080: Steel for the reinforcement of concrete, weldable reinforcing steel
- DIN 488: Reinforcing steels; grades, properties, marking
- EN 10138: Prestressing steels
- DIN 1045-3: Concrete, reinforced and prestressed concrete structures – part 3: Execution of structures
- EN 13670: Execution of concrete structures

(5) GL shall be notified in good time of the standards intended to be used for design, calculations and construction, and their application shall be coordinated with GL.

(6) The materials used during construction, execution and erection shall comply with the standards applied for design and calculations. If materials according to standards other than those mentioned above are used for construction, their compliance with the design codes shall be verified.

3.3.5.3 Raw materials for concrete

3.3.5.3.1 Cement types

The types of cement shall comply with EN 197 or the respective national standards or regulations applying where the concrete is being used. For national standards, compliance with the standards used for design and calculation shall be verified.

3.3.5.3.2 Concrete aggregate

(1) Aggregates shall comply with EN 12620 or the requirements of the national standards or the regulations applying where the concrete is being used. Compliance with the standards used for design and calculation shall be verified.

(2) Aggregates shall not contain harmful constituents in such quantities that the durability of the concrete is adversely affected or corrosion of the reinforcing material is initiated.

(3) Aggregate with alkali-sensitive constituents may not be used as a rule.

(4) Maximum grain size and grading curve of the aggregate shall be selected in accordance with EN 206.

3.3.5.3.3 Added water

The added water shall not contain harmful constituents in such quantities as may impair setting, hardening and durability of the concrete or may initiate corrosion of the reinforcing material. In Europe, drinking water from public supplies is in general suitable for making concrete.

3.3.5.3.4 Admixtures

(1) Concrete admixtures may be used for concrete and cement mortar only if tests have shown that they neither produce adverse changes in important properties of the concrete nor impair the corrosion protection of the reinforcement. Special suitability tests for the concrete to be made may, in individual cases, be required by GL.

(2) Chlorides, chloride-bearing or other steel-corrosion-promoting materials may not be added to reinforced or prestressed concrete.

3.3.5.3.5 Additives

Additives may only be applied to the concrete mix in such quantities that they neither impair the durability of the concrete nor result in corrosion of the reinforcement.

3.3.5.4 Building materials

3.3.5.4.1 Concrete

(1) The composition of concrete shall be so chosen that all requirements regarding the properties of the green and the set concrete are met, including consistency, bulk density, strength and durability plus protection of the steel reinforcement against corrosion. The composition shall be adjusted to the workability necessary for the construction method adopted.

(2) This Guideline is based on the characteristic cylinder compressive strength (28-day strength) f_{ck}. It is defined as the strength figure above which 95 % of the population of all possible strength measurements of the concrete in question may be expected to lie (95 % fractile). This shall be verified with a confidence level of 95 %.

3.3.5.4.2 Concrete-reinforcing steel

(1) This sub-section applies to concrete-reinforcing steel, from coil and mats, used as reinforcement in concrete structures.

(2) Diameter, surface characteristics, strength properties and marking of concrete-reinforcing steels shall correspond to the relevant standards (EN 10080, DIN 488). If welding is to be carried out on concrete-reinforcing steels, only grades suitable for this may be used (e.g. according to DIN 488, Part 1).

(3) Welding of reinforcing steels is in principle allowable. In this case, the S/N curves of welded reinforcing steel (CEB FIP Model Code 1990) shall be applied in the design calculations and the welding shall be performed in accordance with the standards DIN 4099 or DIN EN ISO 17660 by a workshop approved according to these standards.

3.3.5.4.3 Prestressing steel and prestressing procedure

(1) This sub-section applies to wires, rods and braids that are used as prestressing elements in concrete structures.

(2) The properties of the prestressing steel shall correspond to the standards mentioned in Section 3.3.5.2 and shall be proved by certificates from the manufacturer. In particular, data and test results concerning the composition of the steel, mode of production, stress-strain characteristic, elastic limit, yield point, tensile strength, fatigue strength and creep limit shall be submitted. This documentation may be replaced by an approval of the relevant authorities (e.g. European Technical Approval (ETA) or German Technical Approval (“Allgemeine bauaufsichtliche Zulassung”).

(3) For the prestressing procedure (anchors, couplings, grout pipes etc.), an approval (e.g. ETA or “Allgemeine bauaufsichtliche Zulassung”) according to the applicable standards is required.

3.3.5.4.4 Grouting mortar for prestressing systems

(1) The grouting mortar is made from cement, water and admixtures/additions, its function being to ensure a good bond between prestressing elements and enclosing body and to protect the enclosed steel against corrosion, by enveloping the elements and filling up all the spaces inside the sheath.

(2) As a rule, only Portland cement shall be used. Drinking water from public supplies is in the great majority of cases suitable for making grouting cement. Admixtures and additives shall comply with the standards.

3.3.5.4.5 Grout for connections

(1) Grout for connections of precast elements shall fulfil the requirements of the standards on which the calculations are based (e.g. Eurocode 2, in particular the cylindrical compression strength f_{ck}).

(2) The DAfStb guideline “Herstellung und Verwendung von zementgebundenem Vergussbeton und Vergussmörtel” [3.4] by Deutscher Ausschuss für Stahlbeton (DAfStb) is recommended.

3.3.5.4.6 Steel for embedded steel sections and prestressed high-tensile bolts

(1) Embedded steel sections for connections between tubular steel tower and foundation are normally made from steel according to Section 3.3.2.1.

(2) Prestressed high-tensile bolts shall be used in accordance with the standards. Only bolts in strength classes 8.8 or 10.9 shall be used.

3.3.5.5 Durability of the concrete

(1) In order to produce a concrete of adequate durability, i.e. one which protects the reinforcing steel against corrosion and adequately withstands the external and operating conditions to which it is exposed during the anticipated working life of the structure, the following factors shall be taken into consideration:

- selection of suitable raw materials that do not contain any harmful constituents which may impair the concrete’s durability and cause corrosion of the reinforcing material
- selection of a suitable composition for the concrete so that it
  - meets all the criteria laid down for the properties of green and set concrete,
  - can be so poured and compacted that a dense concrete covering layer is formed,
  - withstands internal influences, and
  - withstands external influences, e.g. environmental ones.

- attacks of a mechanical nature
- mixing, pouring and compacting of the green concrete so that the raw materials are distributed evenly throughout the mixture and do not segregate, and a close-grained texture for the concrete is achieved
- curing of the concrete so that in particular the portion near the surface (covering layer) attains the properties to be expected from its composition

(2) Information on defining the environmental conditions for the design can be obtained from e.g. EN 206.

(3) All these factors shall be controlled and verified by the constructor, subcontractor or supplier within their respective zones of responsibility as part of their respective internal surveillance (production control).

3.4 Production and Testing

3.4.1 General

The manufacturers shall ensure that only recognized and approved production processes are used and that the conditions defined as a basis for the recognition and approval are observed.

3.4.2 Welding

3.4.2.1 Prerequisites of the works

(1) Further information on the following sections is given in [3.2]. Furthermore, the welding workshops shall observe the requirements set out in Section 3.2 for the certification of components for wind turbines.

(2) Companies intending to carry out welding shall be approved for such work by a recognized body. According to the German Building Law, proof of welding qualifications as per DIN 18800-7 may be necessary. The companies shall have suitable workshops, facilities, machines and arrangements in the required quantity and scope to ensure competent execution of the welding work. This also includes, for example, machines and facilities for expert preparation of the joints to be welded, operationally safe welding machines and appliances, storage and drying arrangements for welding fillers and auxiliary materials, facilities for preheating and heat treatment, test equipment and materials, as well as weather protection for performing welding work in the open.

(3) For assembly and welding-up, it is recommended that appliances be used to guarantee the dimensional accuracy of the components. The appliances should be such that the weld seams are easily accessible and in the most favourable position for welding.

(4) Within the welding manufacturing procedure, the minimum manufacturer certification is required according to ISO 3834-2. Depending on the complexity and level of difficulty of the structural members and base material, an international welding engineer (IWE) or equivalent qualification may be required by GL for the internal welding supervision at the manufacturer site.

3.4.2.2 Welders, welding supervision

(1) All welding work on components in accordance with Section 3.3.1 shall be carried out only by welders tested in the relevant method, approved by GL or the relevant approval body, and holding valid test certificates. The welders' tests shall be carried out under the supervision of GL or a recognized testing body in accordance with the relevant standards (e.g. EN 287, ISO 9606). Equivalent welders' tests carried out in accordance with other rules or standards by a testing body not connected with the welding company may be recognized.

(2) The period of validity of a welder's test is normally two years. A repeat test may be carried out only for the welding process and the test group in which the initial test was taken. The documents relating to the initial test shall be submitted to GL on request. Any special features of the initial test shall also be included in the repeat test. If a repeat test is carried out with a scope restricted relative to the standards, an originally comprehensive initial test becomes similarly restricted. An extension can only be granted in conjunction with a comprehensive initial test.

(3) Any company carrying out welding work shall have available at least one welding supervisor permanently employed by the company, together with a deputy. Welding supervisors shall have training and experience that meet the requirements of production, and shall provide proof of their professional qualifications. Depending on the type and scope of the welding to be done, the welding supervisor may for example be a specialist welder, a welding technician or a welding engineer. If the welding workshop has been approved by GL, any changes in the welding-supervisory personnel shall be reported automatically. Welding supervisors shall exercise responsible supervision over the preparation and execution of the work.

3.4.2.3 Welding method, welding procedure tests

(1) Only those welding methods shall be used whose suitability for the particular application is known from general experience or has been proved in a welding procedure test.

(2) The scope of testing, test pieces, specimens and requirements for the welding procedure test shall be determined for each individual case on the basis of the base material, welding method and range of application applied for.

3.4.2.4 Welding fillers and auxiliary materials

(1) All welding fillers and auxiliary materials used (e.g. rod electrodes, wire/powder combinations) shall be approved by GL or the relevant approval body. The quality level required depends on the base materials to be welded.

(2) For the choice of welding consumables, the dynamical loading of the welds shall be considered.

(3) Welding fillers and auxiliary materials may also be tested and approved together with the welding method. However, such approval is restricted to the user company and valid for a maximum of one year, unless repeat tests are carried out. Welding fillers and auxiliary materials so tested may be replaced by others which are equivalent and have been approved by GL with a corresponding quality level, if this is expressly stated in the procedure approval.

3.4.2.5 Weld joint design

(1) The welds shall be planned right from the beginning of the design stage so as to be easily accessible during production and any testing that may be necessary, and to permit their execution in as favourable a sequence and position as possible. In this context, it shall be ensured that the internal stresses and distortions remaining in the components after fabrication are as low as possible. Small distances between welds and local concentrations of welds shall be avoided.

(2) For welding in cold-worked areas, the minimum bending radii (e.g. according to DIN 18800) shall be observed.

(3) Butt-welded joints (e.g. square, single- or double-V butt welds) and corner or cross welds (e.g. single- or double-bevel welds) should be so planned that it is possible throughout to weld through the full cross-section of the plate or profile. To this end, the components shall be prepared for appropriate types of seam, depending on plate thicknesses, according to the international standards (e.g. DIN EN ISO 9692) with an adequate aperture angle, sufficient air gap and as narrow a root face as possible.

(4) Depending on the welding method, the root shall generally be grooved out on the rear side before the capping passes are welded. Special forms of seam require the consent of GL; if necessary, the form of seam will be determined in conjunction with a welding procedure test.

(5) Fillet welded joints shall be made continuous on both sides wherever possible. The seam thickness depends on the particular load, and shall be verified by calculation as a rule. The a-dimension shall not exceed $0.7 \cdot t$ (where t = thickness of the thinner section). Except in the case of walls and similar light-gauge components, a fillet weld shall not be less than 3.0 mm thick.

(6) Overlap joints should only be used for relatively low-stressed components and if possible only parallel to the direction of the principal stress. The width of the overlap shall be at least $1.5 \cdot t + 15$ mm, where t is the thickness of the thinner plate. The fillet welds shall be made in accordance with the above specifications. In the case of joints between bars in a lattice structure, the requirements according to DIN 18800-1 apply.

3.4.2.6 Execution and testing

(1) Around the area of the weld, the components shall be clean and dry. Scale, rust, slag, grease, paint (except shop primers) and dirt shall be removed carefully prior to welding. If plates, sections or components have a corrosion-reducing shop primer applied before welding, this shall not impair the quality of the welded joint. Shop primer materials shall be approved by GL or the relevant approval body for welding-over.

(2) When preparing components and fitting them together, care shall be taken to ensure that the prescribed joint geometry and root face (air) gaps are maintained. Where the permissible root face gap is exceeded slightly, it may be reduced by build-up welding at the flanks of the seam. Inserts or wires may not be welded into the gap. Larger gaps may be closed by welding-in a sufficiently large plate strip or profile section.

(3) Plates and sections shall be aligned precisely, especially where joints are interrupted by transverse members. The maximum permissible edge mismatch is 10 % of the plate or section thickness, up to a maximum of 3 mm. GL may demand tighter tolerances, e.g. for reasons of fatigue strength.

(4) The working area shall be protected against the weather during welding. At low temperatures (less than 5 °C), appropriate measures shall be taken to ensure faultless execution of the welds. At temperatures below –10 °C, welding shall cease. Rapid cooling shall be avoided; if necessary (i.e. depending on the type of material, component thickness, ambient temperature), preheating shall be carried out before welding.

(5) Welding work should be performed in the most favourable welding position. A suitable construction and welding sequence shall be chosen to allow the parts to shrink with as little resistance as possible and to minimize the contraction stresses.

(6) When welding, care shall be taken to achieve uniform penetration, thorough fusion and uniform low-profile seam surfaces with a notch-free transition to the base material. In multi-pass welding, the slag from preceding passes shall be removed carefully. Cracks (including cracked tack welds), large pores or slag inclusions etc. may not be welded over; they shall be removed.

(7) Repair of major defects in material or workmanship may only be undertaken with the consent of GL. Minor surface flaws should if possible be removed by shallow grinding. Deeper faults shall be machined out cleanly and rewelded. In the case of cracks, if complete or partial replacement of the component is not required and cracks are to be welded-up with the consent of GL, the length and course shall be clearly established by means of a suitable test method. The crack shall be machined out to beyond its ends and then welded-up.

(8) Competent, faultless and complete execution of the welds shall be ensured by careful in-house monitoring. GL checks the welding work on a once-only basis during Implementation of design-related requirements in Production and Erection (see Section 1.2.2.5 / Type Certification), on a random-sampling basis during manufacture (see Section 1.2.3.5 / Project Certification), and if appropriate during the final inspection following completion. GL may reject components which have not been adequately monitored and demand resubmission after successful monitoring and, if necessary, corrective measures by the company.

(9) In cases of doubt, GL may call for additional tests (e.g. non-destructive tests to prove faultless seam quality) of important components. The type and scope of the tests is laid down by GL individually for each case.

(10) The scope of non-destructive testing and inspections shall be applied according to Table 3.4.1. The classification of the welds shall be agreed with GL.

Table 3.4.1 Minimum scope of non-destructive inspections and tests of welds

Category / Type of connection	Special / Primary structural weldings			Secondary structural welding		
	RT	UT	MT	RT	UT	MT
Butt welds	10 %[2]	100 %[2]	10 %	spot	spot	spot
T-joints (full penetration)	—	100 %	100 %	—	spot	5 %
T-joints	—	[3]	100 %	—	—	spot
Fillet welds	—	—	10 %	—	—	spot

[1] All welds which will become inaccessible or very difficult to inspect in service are to be non-destructive tested over their full length

[2] Up to weld thickness of 30 mm ultrasonic testing (UT) may be replaced by radiographic testing (RT) up to an amount of 100 %

[3] Where partial penetration T-joints are admissible in highly stressed areas, an ultrasonic testing to determine the size of incompletion and the soundness of the welds may be required.

(11) All welds shall meet the requirements of quality class B according to DIN EN ISO 5817. Accordingly, EN 12062 or equivalent shall be used to define additional quality classes according to other standards.

(12) If impact tests are to be performed, the specimen position of the notched bar impact test shall be in line with [3.2]. Figures 1.3 and 1.4 of [3.2] show the position of the specimen depending on the heat input, plate thickness and weld preparation.

3.4.2.7 Post-weld treatment

(1) In case of fatigue life improvement by post-weld treatment, a negative influence on the mechanical properties of the weld connection is not acceptable. Verification may be required by GL.

(2) The quality control shall be guaranteed. Further, the effect of post-welding treatment must be inspected to 100 %.

(3) The mode of operation of the post-weld treatment procedure shall not be influenced by corrosion.

(4) The proof of effectiveness of a post-weld treatment procedure shall be inspectable and testable.

(5) A positive effect of post-weld treatment can be considered for the fatigue life calculation, provided that the post-weld treatment procedure is accepted by GL.

3.4.3 Laminating fibre-reinforced plastics

3.4.3.1 Requirements for manufacturers

(1) All workshops, store-rooms and their operational equipment shall meet the requirements of the national laws, regulations and standards. The responsibility for compliance with these requirements is solely the manufacturer's.

(2) The danger of contamination of materials for laminating shall as a rule be kept to a minimum by rigorous separation of production areas and other workshops as well as store-rooms. Only the quantity of materials required for production within the next two days shall be stored in the laminating workshops.

(3) Whilst laminating and gluing is progressing, dust-generating machinery may be operated in the laminating workshop only to a limited extent and only if fitted with a dust collection unit. In such a case, any influence on product quality by dust has to be ruled out. Painting or spraying work is only permissible within the laminating workshop if the manufacturer can ensure that such activities will not affect the laminating quality.

3.4.3.2 Laminating workshops

(1) Laminating workshops shall be totally enclosed spaces capable of being heated as well as having ventilation supply and exhaust equipment. A shop room temperature between 16 °C and 30 °C with a maximum relative humidity between 20 % RH and 80 % RH shall be maintained as a rule during laminating work and curing. If the manufacturers of the laminating resins or adhesives have specified other processing temperatures, these shall apply.

(2) Thermographs and hygrographs shall be provided for monitoring the climatic conditions, whereby it shall be possible to read off the climatic conditions directly at any time. The location of the instruments shall be agreed with GL, their number and arrangement depending on the operational conditions. The instruments shall bear valid calibration marks; the records on the climatic conditions shall be kept for a period of at least 10 years and submitted to GL on demand.

(3) The provision of ventilation supply and exhaust equipment shall be such that an impairment of the materials is excluded and e.g. no unacceptable amounts of solvent are extracted from the laminate.

(4) The work places shall be illuminated in a suitable manner, precautionary measures being taken to prevent the controlled curing of the laminating resin from being impaired by sun radiation or the illuminant.

(5) The laminating workshops shall be of adequate size (floor area and ceiling height), in order that the components are easily accessible and the intended production processes can take place without hindrance.

3.4.3.3 Store-rooms

(1) Laminating resin compounds and adhesives shall be stored according to the manufacturer's instructions. The temperature in the store-rooms shall be recorded continuously.

(2) Prepregs shall be stored in special refrigerated compartments in accordance with the manufacturer's instructions. The temperature shall be recorded continuously.

(3) Reinforcing materials, core materials, fillers and additives shall be stored in closed packages, in such a way that degradation caused by dust, temperature, humidity etc. is prevented. Moisture sensitive materials exposed to air humidity shall be stored in spaces with continuous moisture recordings and humidity shall not exceed 70 % RH, and 80 % RH only for short periods.

(4) Storage shall be arranged in such a way that the designation of the materials, and the storage conditions and maximum storage periods (expiration dates) prescribed by the manufacturer, are easily visible. Materials whose storage period has been exceeded shall be marked as being prohibited for use and then removed from the store as soon as possible, or shall be kept in a clearly distinguished exclusion area.

(5) Quantities of materials to be processed shall be brought to the processing rooms in good time to allow the whole material volume to reach the processing temperature ($\Delta T \leq 2$ °C) with the packaging remaining sealed.

Note:

This temperature adjustment is necessary to ensure that the dewpoint is not reached.

(6) Packages removed from store and opened may be returned to store only in defined cases (e.g. hot-curing prepregs). The packages have to be clearly designated in such case.

3.4.3.4 Processing requirements

(1) If rotor blades, shafts or other components are manufactured from FRP for mounting on or installation in wind turbines and if an application for project certification has been submitted for the wind turbine, then as a matter of principle only materials approved by GL shall be used for production. As well as suitable and approved materials being selected, their processing shall be treated with special care because of its significant influence on the properties of the product.

(2) Prior to the commencement of production, the manufacturer shall convince himself that the materials can be combined and are suitable for the intended process.

(3) For the preparation and processing of the resin compounds, the instructions of the material manufacturer plus any other applicable regulations, such as those of the relevant safety authorities, shall be observed in addition to this Guideline.

(4) Resin and reaction agent shall be mixed in such a way that a homogeneous mixture is achieved. Any intrusion of air shall be avoided in order to prevent influences on product quality. There may be cases where degassing of the resin compound under vacuum is necessary.

(5) If rigid plastic foam is used as the core material, this shall be degassed beforehand and if necessary tempered. In particular for slotted core materials, it shall be ensured that the material properties which were established as a basis within the scope of verification are achieved during the processing activities.

(6) During production, the processing time for the mixed resin compound specified by the manufacturer shall not be exceeded. In the absence of such information, the pot time shall be established in a preliminary test and the processing time then laid down in consultation with GL.

(7) It is not possible for this Guideline to cover all the details of every production process. Deviation from this part of the Guideline is therefore possible after consultation with GL.

(8) Prior to the start of laminating work, the mould surfaces shall be treated with an adequate quantity of a suitable release agent and brought up to the planned processing temperature. The surfaces shall be dry and dust-free. Release agents containing silicone are inadmissible.

3.4.3.5 Building up the laminate

(1) If surface protection is to be achieved by means of a gelcoat, the resin shall be applied in a uniform layer of thickness in accordance with the production specification, using a suitable process.

(2) It must be verified that the gelcoat / reinforcement layer design and application sequence / process provide the interface adhesion between gelcoat and structural laminate. Thus, the first layer of laminate shall be applied to the gelcoat when it is gelled but not fully cured. For this, a reinforcement layer of low surface weight and high resin content (e.g. in the case of glass fibre, max. 300 g/m² and 35 % glass by weight) shall be used.

(3) The laminate shall be built up in accordance with the approved production specification. The reinforcement layers shall be adequately deaerated and compressed so that the required fibre content is attained. Resin enrichment shall be avoided.

(4) The maximum thickness of the material that can be cured in one step is determined by the maximum permissible heat generation. In the case of vacuum bagging, the decisive factor as a rule is the maximum number of layers from which air can still be totally removed.

(5) If the laminating process is interrupted for more than two days in the case of widely used cold-curing resins, the surface of the cured laminate shall be roughened and cleaned to obtain a surface providing adequate bonding. Deviating manufacturer's instructions (e.g. in the case of polyester resins with skin-forming additives) shall be followed.

(6) Transitions between different thicknesses of laminate shall be made gradually. The minimum value of the step length L [mm] for a laminate layer with a thickness d [mm] and an average fracture stress S [N/mm²] can be determined as follows:

$$L = (S/10\ \text{N/mm}^2) * d$$

The formula may only be applied for laminate layers with a surface weight of up to 1300 g/m². In case of higher surface weights, a separate proof is necessary.

In the area close to the blade root, lower step lengths are generally allowable.

If the attachment or cutting of reinforcement layers is unavoidable, e.g. in the case of complicated mouldings, then cut edges shall overlap or reinforcement strips shall be provided. In the butt or seam region of laminates, any reinforcement layer shall overlap by at least the value specified above for the step length.

Multiple overlaps or butts at the same position (i.e. more than 20 % of the total layers' thickness at the respective position) are not allowed.

(7) In the transition region from a sandwich construction to solid laminate, the core material shall be tapered with a gradient of at maximum 1 : 3.

The tapering of core material depends on the magnitude and direction of the load. In the main load-carrying direction, the tapering of the core should be between 1:3 and 1:10, depending on the local strain level. Perpendicular to the main load-carrying direction, the tapering of the core material should be at maximum between 1:3 and 1:5, depending on transversal strain level.

(8) Parallel or insert linings shall be free from moisture and impurities. Their surfaces to be bonded to the laminate shall be prepared suitably (see Section 3.4.4.2, para 1).

3.4.3.6 Curing and tempering

(1) Components may only be removed from the moulds after adequate curing of the resin and the adhesive. The required curing time depends on the forces that may occur due to the separation of the component from the mould, the curing temperature and the resin systems used. The curing time shall be verified by experiment and documented.

(2) Resin systems which cure under pressure, UV radiation and/or increased temperature shall be treated in accordance with the manufacturer's instructions or the results of suitable previous investigations.

(3) Immediately following curing, the components shall receive post-curing (tempering) at elevated temperature. The maximum allowable temperature is determined by the materials (e.g. PVC foam) in the component, whilst the heat distortion temperature of the structural resins may not be exceeded. Cold-curing systems which are not subsequently tempered shall be stored for 30 days under curing conditions. This period may be reduced with the consent of GL, provided the relevant manufacturer's instructions for post-curing are available or confirmed experimental post-curing values can be presented.

3.4.3.7 Sealing

(1) Laminate surfaces without surface protection shall be sealed after curing/tempering, using suitable agents. In particular, the cut edges of cut-outs and glued joints shall be carefully protected against penetration by extraneous media (e.g. moisture).

(2) The sealing materials used shall not impair the properties of the laminate. They shall also suit the intended purpose of the component.

3.4.4 Adhesive bonding

3.4.4.1 Adhesive joints

(1) Adhesive joints for load-bearing parts shall generally be verified by tests to be agreed on for each individual case, unless comparable experience is available.

Note:

Particularly in the case of highly thixotropic adhesives, prior proof of their suitability shall be given with due consideration of the production process.

(2) A specification for production and testing shall be compiled for the adhesive joints of load-bearing structures. In particular, the nominal values and tolerances of adhesive-layer thicknesses as well as the maximum size and extent of permissible flaws shall be defined. The adhesive layer thicknesses, tolerances and the maximum size and extent of permissible flaws shall be considered during the computational verification of the adhesive joint (see Section 5.5.6).

(3) Only adhesives with confirmed properties may be used for bonding. The adhesives may not have any negative effects on the materials to be joined.

(4) The possibility of contact corrosion (bond-line corrosion) shall be countered by suitable means.

(5) If FRP components are to be bonded and a resin system differing from the laminating system is used, the components shall be totally cured before bonding.

3.4.4.2 Assembly process

(1) The various surface pretreatments for synthetic materials and metals are for example compiled in VDI 2229 and VDI 3821.

(2) The surfaces of the materials to be bonded together shall be dry and free of release agents (wax, grease, oil etc.), impurities (dust, rust etc.) and solvents. Especially when using solvents for cleaning purposes, compatibility with the material and sufficient ventilation time shall be ensured.

(3) All surfaces to be bonded shall be roughened either mechanically (rough-grinding, sand-blasting etc.) or chemically by etching in advance. It is absolutely necessary that layers on the surface of the materials to be bonded that exert a negative effect on the bonding process (e.g. skin-forming additives in polyester resins or residues of peel ply in the case of FRP, or oxide layers in the case of aluminium) be removed.

Note:

As a rule, additional roughening is also required when peel ply is used. If alternative means are to be applied in order to avoid roughening, a test of the procedure is required.

(4) The adhesive shall be processed in accordance with the manufacturer's instructions; the proportion of fillers may not exceed the permitted limit. The adhesive shall be mixed in such a way that a homogeneous mixture is achieved. Any intrusion of air shall be avoided in order to prevent influences on product quality. There may be cases where degassing of the adhesive under vacuum is necessary.

(5) The adhesive shall be applied evenly and as bubble-free as possible to the materials to be joined. If highly thixotropic adhesives are used, it is advisable to apply a thin undercoat of the corresponding pure resin system to the surfaces to be joined.

Note:

In many cases, an increase in the strength of the bonded connection can be achieved by the use of specially matched primers. The use of primers is particularly recommended for bonded joints which later in service are exposed to environmental influences.

(6) Following application of the adhesive, the materials to be joined shall be brought together without delay and fixed in place.

(7) A loading of the adhesive joint before the adhesive has cured sufficiently is inadmissible (see Section 3.4.3.6, para 1). For all adhesive joints with thermosetting adhesives, subsequent tempering of the joint is recommended; in the case of cold-curing adhesives, tempering is necessary as a rule (see Section 3.4.3.6, para 3).

(8) After curing, the adhesive joint shall be protected by suitable means against penetration by extraneous media (e.g. moisture).

3.4.5 Manufacturing surveillance for FRP

3.4.5.1 General

(1) A manufacturing surveillance of FRP components by GL requires a shop approval (see Section 3.1.4) as well as material approvals (see Section 3.3.3.8).

(2) Manufacturing surveillance of FRP components comprises quality control of the raw material, surveillance during production, and checking the quality of the completed components.

(3) A distinction is made in manufacturing surveillance between internal and external surveillance. External surveillance in the sense of this Guideline means regular random-sampling checks of the internal surveillance and of the component quality by GL or a body recognized by GL.

(4) GL reserves the right to make unannounced inspections of the works. The manufacturer shall allow the representative of GL access to all spaces serving the purposes of manufacture, storage and testing and shall permit him to examine the available production and testing documentation.

(5) In the case of companies manufacturing components in series with a certified quality management system, external surveillance is usually limited to inspections at set intervals to be prescribed.

(6) For companies which have production and witnessing documentation assessed by GL that exceeds the requirements as per Section 3.4.5.1, para 5, and have concluded an agreement with GL on the reporting of production changes, production deviations and claims, a works expert can be appointed and notified by GL to be responsible towards GL for the surveillance during production.

3.4.5.2 Incoming inspection

(1) The characteristic values and properties of the materials shall be verified by the manufacturer by means of inspection documents. The following inspection documents according to EN 10204 (ISO 10474) are required as a minimum:

EN 10204-2.2	Fibre products, gelcoat resins, paints
EN 10204-3.1	Laminating resins, prepregs, core materials, adhesives

(2) During the incoming inspection, the goods shall at least be checked for any damage and for compliance of the details in the certificates with the requirements. Material values should be checked by random sampling.

(3) The goods shall be stored in accordance with the requirements of the manufacturer and this Guideline.

3.4.5.3 Production surveillance

(1) Details of the production process shall be laid down by specifications which also contain specimen documents for production and testing of the components. The tasks and responsibility of the production and quality control departments shall be defined clearly.

(2) As the work progresses, the individual production steps shall be signed by the employees responsible for each stage on the basis of the prescribed documentation.

(3) The persons entrusted with production shall be trained in accordance with their task, and shall work under professionally qualified supervision. For adhesive joints, the manufacturing shop needs to prove that at least two persons working in production have undergone an appropriate education in adhesives by a suitably qualified organisation. Additionally, the personnel to manufacture the adhesive joints shall have undergone suitable training.

(4) The batch numbers of the materials used in the component shall be given in the production documentation, in order that they can be traced back to the manufacturer if need be. Reinforcing layers introduced into the laminate shall be checked off immediately during the production process, with indication of the fibre direction.

(5) From every batch of reaction resin compound, a sample shall be taken and tested. If mixing machines are used, at least one sample per joining process (interruptions of up to one hour can be neglected) shall be taken. The same applies for any change at the mixing machine or any of the components of the compound. The samples shall be checked for their networking degree and the results shall be recorded.

Note:

Storage of retain samples for at least the duration of the warranty period is recommended.

(6) On request by GL, reference laminates of about 50 x 50 cm shall be produced in parallel. This shall result in confirmation of the material values used as a basis for the strength calculations.

3.4.6 Wood processing

3.4.6.1 Manufacture of wooden rotor blades

3.4.6.1.1 General

(1) Apart from the selection of suitable and approved materials, their processing is of particular importance because of its significant influence on the properties of the product.

(2) In the preparation and processing of the components, the directions of the manufacturers of the raw material and the requirements of the relevant safety authorities and employers' liability insurance associations shall be taken into account together with this Guideline.

(3) It is not possible for this Guideline to cover all the details of every mould and production process. Deviations from this Guideline are therefore possible with the consent of GL.

(4) Details of the production process shall be laid down in the form of checksheets or work progress slips, samples of which shall be enclosed with the quality manual. These shall be signed off by the employees responsible for each stage as the work progresses.

3.4.6.1.2 Mould requirements

The moulds for laminated-wood rotor blades shall, in addition to a high degree of dimensional accuracy, have sufficient rigidity to eliminate the risk of unacceptable deformation during the manufacturing process. Equipment shall be provided to ensure perfect joining when sub-structures are glued together.

3.4.6.1.3 Preparing the wood

(1) Pre-sorting shall be used to ensure that the sawn timber meets class S 13 according to DIN 4074-1 or a comparable quality standard according to other regulations.

(2) Prior to further processing, the mean moisture content shall be determined. It should be 10 % ± 2 % as the mean of 10 typical random samples. Under no circumstances may the variation in moisture content between individual samples exceed 4 %.

(3) When boards are processed into solid-wood rotor blades, this moisture content is generally achieved by chamber drying. Veneers used for the manufacture of moulded laminates shall, if supplied in dried condition, be stored in such a way that their moisture content does not exceed the stated tolerances.

(4) For good conformability, boards shall be planed on all sides. Rough-sawn boards shall not be permitted to reach the bonding stage.

(5) Secondary sorting shall be undertaken once the boards have been planed. Individual fault areas may be cut out.

3.4.6.1.4 Layer build-up and bonding

(1) Glueing of the wood shall be carried out as soon as possible after planing to prevent fouling of the surfaces to be glued and deformation as a result of subsequent shrinking or swelling.

(2) All components used for processing should be at room temperature. The ambient humidity of the room shall be adjusted so that the required moisture content tolerances are observed.

(3) The boards shall be oriented with their layers in such a way that the risk of the glued joints cracking open is kept to a minimum. Longitudinal butt-joints of individual boards shall be made as dovetail joints of load group I according to DIN 68140. It shall be ensured in the layering that there is sufficient offset of the longitudinal joints.

(4) If cross-sections with a width greater than 22 cm are being produced, each layer shall have several boards in parallel so arranged that there is sufficient overlap between the longitudinal joints within the layer.

(5) When processing veneers, either butt- or scarf-joints are permitted, provided care is taken to ensure an adequate overlap of the joints in the layers. The glue shall be applied evenly and in accordance with the manufacturer's instructions. To achieve a glue coating of constant high quality, automation of the glue application process is required.

(6) The boards to be glued shall be kept under pressure while the glue cures. The manufacturer's instructions shall be observed.

(7) When processing veneers into moulded wood laminate, vacuum processes should preferably be used. The glueing of such part-skins shall be carried out following the pattern for glueing boards. Part- and half-skins shall be held in the desired position by suitable aids so that adequate dimensional accuracy is achieved.

(8) The temperature for glueing shall be at least 20 °C. Glueing temperatures up to 50 °C may be used to reduce the curing time.

3.4.6.1.5 Wood preservation

When boards have been glued together or half-skins have been produced, any hollow spaces shall be treated with wood preservative. This also applies to subsequently mechanically machined areas, such as drillings and millings for connection elements where the blade is joined to the hub.

3.4.6.1.6 Surface protection

(1) The wood surface to be treated shall be even and free from cracks. Small surface defects in the wood shall be eliminated in a competent manner.

(2) Materials for providing protection against moisture shall be processed and applied according to the manufacturer’s instructions. Effective protection of the surface usually requires application of several coats.

(3) Textile inserts shall be incorporated in the surface coating in accordance with the processing rules for FRP rotor blades (see Section 3.4.3.5, para 2).

3.4.6.1.7 Blade connections

(1) Connections between the rotor blades and the hub shall be so designed that reliable load transfer is guaranteed. It is particularly important to ensure that the differences in elastic properties between wood, the connection elements and if applicable synthetic resins, are compensated for in the design. In addition, joints between the wooden blade, the connection element and the hub shall be protected effectively against the penetration of moisture into the wood.

(2) Because of the multiplicity of design possibilities, no generally applicable requirements for the protection of the joints are stated in this Guideline.

3.4.6.2 Manufacturing surveillance of wooden rotor blades

3.4.6.2.1 General

(1) The component properties of wooden rotor blades depend not only on the quality of the raw materials but also on their processing. Furthermore, the possibilities of checking the properties and discovering possible defects are more restricted at a later stage. It is therefore not sufficient just to test the raw material or the finished product; continuous surveillance during production is required.

(2) In manufacturing surveillance, a distinction is made between internal and external surveillance. External surveillance in the sense of this Guideline means regular checks (see Section 3.1.4 / Shop approval) of the internal surveillance and quality control.

3.4.6.2.2 Incoming inspection

(1) Proof of the characteristic values and mechanical properties laid down in the material approval procedure shall be provided by the manufacturer in a test report. In the case of wood, sorting class S 13 shall be verified in writing by the supplier.

(2) As part of the incoming inspection, the accompanying documentation shall be checked for conformity with the requirements, and the materials shall be stored in accordance with this Guideline and entered into the inventory file.

3.4.6.2.3 Visual checks

During and on completion of the production process, the component shall be visually checked. Attention shall be paid to completeness of glueing, flaws in the surface of the wood etc.

3.4.7 Making and working the concrete

The production of concrete shall be in accordance with EN 206 or DIN 1045-2. The execution of concrete structures shall be carried out according to EN 13670 or DIN 1045-3. The essential steps are listed in the following.

3.4.7.1 Proportioning and mixing the raw materials

(1) Mixing instructions, containing precise details of the type and quantity of the raw materials for the concrete mix to be produced, shall be available in writing.

(2) The raw materials shall be proportioned by weight.

(3) They shall be mixed in a mechanical mixer until a uniform mixture has been produced.

3.4.7.2 Transport, pouring and compacting

(1) The type of delivery and composition of the concrete shall be matched to prevent segregation.

(2) In pedestal- and wall-shuttering, down pipes ending just above the working point shall be used.

(3) Discharge pipes for pumped concrete shall be run in such a way that there is no break in the concrete flow within the pipes.

(4) The reinforcement rods shall be tightly encased in concrete.

(5) The concrete shall be completely compacted.

(6) The individual sections for concreting shall be determined before concreting starts.

3.4.7.3 Curing

(1) In order to attain the properties expected of the concrete, especially in the surface region, careful curing and protective measures are required for a significant period.

(2) Curing and protection shall be started as soon as possible after the concrete has been compacted.

(3) Curing prevents premature drying-out, particularly due to sunshine and wind.

3.4.7.4 Concreting in cool or hot weather

(1) In cool weather and in frost conditions, the concrete shall be poured at a specified minimum temperature and protected for a certain length of time against heat loss and drying-out.

(2) Green concrete shall not be added to frozen concrete. Aggregate may not be used in the frozen condition.

(3) In hot weather, account shall be taken of the effect of the sun on the green concrete (e.g. by covering it over).

(4) The temperature of green concrete can be lowered by chilling the aggregate and the water to be added.

3.4.7.5 Formwork and its supports

3.4.7.5.1 Forms

(1) Forms and boxing shall be made as dimensionally accurate as possible and tight enough to prevent the fine mortar of the concrete flowing out through the gaps during pouring and compacting.

(2) Forms and their supporting structure shall be so dimensioned that they can safely absorb all forces that may arise until hardening has occurred, account being taken also of the effect of the pouring speed and the type of compaction of the concrete.

(3) If slip forms are used, the basic principles of this process shall be observed, as described for example in the data sheet “Gleitbauverfahren” (“Slip forming technology”; Deutscher Beton- u. Bautechnik-Verein e.V.).

3.4.7.5.2 Stripping

Stripping may only be carried out after the concrete has attained sufficient strength as regards the load-carrying capacity and resistance to deformation of the component, and after the form is no longer needed for curing purposes.

3.4.7.6 Quality control

3.4.7.6.1 General

(1) The application of a quality management system in accordance with ISO 9001 is described in Section 3.2.

(2) This section contains a minimum of necessary control measures for the planning and construction of concrete structures. They comprise the important measures and decisions plus the necessary tests in connection with the construction regulations, standards and the generally accepted state of the art which together are important for the adherence to the prescribed requirements.

(3) Surveillance of manufacturing and construction comprises all measures for compliance with and control of the required quality of the building materials and the workmanship. It consists of checks by visual inspection and testing, and also includes evaluation of the test results.

(4) Surveillance of manufacturing and construction comprises:

- suitability tests and methods of control
- tests and checks during construction
- final inspections and final checks

If necessary, suitability tests shall precede the start of construction, in order to ensure that the planned structure can be erected satisfactorily using the prescribed building materials, equipment and manufacturing procedures.

(5) The quality and compatibility of the materials with the raw materials of concrete, mortar etc. should be ensured either on the basis of previous experience or by tests carried out.

(6) Only standardized building materials should be used.

(7) The checks required are summarized in Table 3.4.1.

3.4.7.6.2 Tests during construction

(1) General requirements:

- Dimensions, properties and suitability of the building materials, fixtures in the structure and the appliances fitted shall be surveiled continuously.
- The building materials and components delivered to the building site shall be checked against the order specification.
- Important findings shall be entered into written records (e.g. the construction logbook) and made accessible to all concerned.
- Depending on the required reliability level, special checks may be agreed additionally.
- For the quality control of concrete, EN 206 applies.
- For all other building materials or other materials, reference shall be made to currently valid technical documentation.

(2) Acceptance checks for site deliveries

- For the delivery note of ready-mixed concrete, EN 206 applies.
- For prefabricated parts, the delivery note shall certify that they were made, marked and treated in accordance with the order specification.
- The delivery notes for reinforcing steel shall contain the following information:
  - steel in bundles, in coils or under the usual conditions of structural steel engineering
  - bars or welded-up reinforcing-steel mats
  - steel cut to length and bent
  - prefabricated reinforcement
- Origin and characteristics of the delivered steel shall be known for the entire reinforcement.
- For prestressing steel and prestressing equipment, EN 1992 (Eurocode 2) applies.

(3) Checks:

- Regarding checks prior to concreting, see EN 206.
- Before inserting the prestressing elements, a check shall be made to see whether any damage has occurred in the works or after arrival on the site.
- It is recommended that a general check be made before starting the prestressing to see whether the entire prestressing process can be carried out without hindrance.
- A prestressing report shall be compiled on the measurements made during the individual prestressing steps (jack force, extensions, anchor slippage etc.).
- The interval between prestressing and completion of the protective measures for the reinforcing steel (grouting) shall be checked and recorded.
- During grouting, it is necessary to check the injection pressure, the unimpeded flow of the grouting mortar from the vents, the amount of mortar coming out of any leakage points and the amount of mortar injected, as well as to take samples for checking the consistency and water loss. If necessary, the strength of the mortar should be checked.

Table 3.4.1 Items to be checked during manufacturing and construction (taken from EC 2, Section 7)

Item	Control of building materials and material production	Control during construction
Concrete	Raw materials Composition Production Green concrete Cured concrete	Transport, pouring Compacting Curing Surface treatment
Forms and supports	Material properties	Solidness Assembly, dismantling Camber Deflections Foundations Tightness Surface finish on concrete (inner) side
Reinforcement	Laid-down raw-material properties Surface finish	Treatment and storage Cutting to length Assembly, reinforcement Overlapping- and other end joints Welds Laying Concrete cover
Prestressing steel and prestressing gear	Laid-down raw-material properties Surface finish Prestressing gear Straightness of prestressing elements Grouting mortar	Treatment and storage Cutting to length Laying Prestressing gear Prestressing Grouting
Components, prefabricated parts	—	Dimensional deviations Camber and deflections Deviations from order specification

3.4.7.6.3 Conformity checks

(1) By conformity checks are meant all measures and decisions whose observation ensures that all prescribed requirements, criteria and conditions are entirely complied with. This includes the completion of the relevant documentation.

(2) For conformity checks for concrete, see EN 206.

(3) Conformity checks for other building materials shall be based on international standards or, if these do not exist, on national standards or approvals.

3.4.7.6.4 Inspection and maintenance of the completed structure

(1) Special checks (inspections) to be carried out during service shall be laid down in an inspection programme.

(2) All information required for utilization and maintenance should be at the disposal of whoever has responsibility for the entire structure.

Rules and Guidelines
IV Industrial Services

1 Guideline for the Certification of Wind Turbines

4 Load Assumptions

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4.1 Fundamentals

4.1.1 General

(1) The following sections explain the requirements for the determination of the loads resulting from the environmental conditions in conjunction with the operational behaviour of the wind turbine.

(2) Load assumptions of the following guidelines are accepted to reach the required load and safety levels:

- IEC 61400-1, Edition 2, 1999 [4.1]
- IEC 61400-1, Edition 3, 2005 [4.4], including IEC 61400-1/A1, 2008 [4.5] in combination with GL Best Engineering Practice [4.6]
- DIN EN 61400-1, 2006 [4.7], including IEC 61400-1/A1, 2008 [4.5] in combination with GL Best Engineering Practice [4.6]
- DIBt Richtlinie für Windenergieanlagen [Guideline for Wind Turbines], 2004 [4.2], see also Appendix 1.A

(3) The external conditions are classified according to intensity, and can be selected to match the desired requirements as a design basis for calculation of the loads. Extreme climatic or terrestrial conditions at the installation site shall be considered separately and formulated as site design conditions. The requirements for this are defined.

(4) Load calculations for wind turbines with concepts other than horizontal axis, two- or three-bladed, non-shrouded and generator-coupled shall be agreed in consultation with GL.

4.1.2 Assessment documents

For the assessment of the load assumptions, the following documents are needed:

a) drawings with principal dimensions and a compilation of the masses, mass moments of inertia, and centres of gravity. For the rotor blades and the tower, complete details of the geometry and mass distribution are needed. For the geometry of the rotor blade, this includes in particular the twist, chord length, profile thickness and profile type.

b) the characteristic quantities of those electrical components (e.g. positioning drives, generator etc.) which have an influence on the dynamic behaviour of the turbine (see also Chapter 7 and Chapter 8)

c) a power curve as the result of the calculations in normal operation between V_{in} and V_{out} with application of a steady wind model

d) aerodynamic data for the profile types used (lift, drag and moment coefficients) in relation to the angle of incidence over 360° for the Reynolds numbers and profile thicknesses. A 3D correction shall be performed for load cases with the wind turbine in operation.

e) physical environmental parameters (e.g. air density, dynamic viscosity etc.). At locations with extreme temperatures, the remarks in Section 4.4.5.4 and 4.4.5.5 shall be observed.

f) documents on transport and erection procedures: details on special turbine states, and specification of the corresponding maximum permissible average wind speeds for erection and maintenance. Here the dimensioning loads for the locking of moving components (e.g. blade, rotor and yaw bearing lock) shall be specified.

g) description and, if applicable, a sketch of the coordinate systems used, with the position of coordinate origins (see Appendix 4.A)

h) For all elastically modelled components (e.g. rotor blade, drive train, tower, foundation etc.), the mass distribution, stiffnesses, natural frequencies and dampings used for the calculation shall be specified in the case of stresses determined by computational means.

i) A resonance diagram (e.g. Campbell diagram) shall be given, containing the natural frequencies to be considered (e.g. rotor blade, drive train, tower) and the relevant excitations (e.g. rotor speed 1P, 3P, 6P etc.).

j) For operation within the resonance range of the tower (see Section 6.6.5.1), the description of the functional principle and criteria for the application of vibration monitoring as well as the prescribed triggering values shall be specified (see also Sections 2.3.2.8 and 4.3.4.3).

k) a table of the wind speeds used in the calculations

l) detailed description of the calculated load cases and the evaluation of extreme and fatigue loads (see Appendix 4.B)

m) the braking torque curve of the mechanical brake

n) The assessment documents shall be accompanied by a description of the functional principle of the wind turbine and of all parts of the control and safety systems which exert an influence on the load response of the wind turbine. The scope and informational content of the documents to be submitted in this regard are given in Section 2.1.2. Appendix 2.B provides tables that summarize the main load assessment relevant parameters as an expedient for data submission. The use of the tables is optional.

o) documentation on the controller (see Section 4.5)

p) detailed descriptions / assumptions of the pitch actuator details and blade pitch bearing friction parameters, e.g. pitch rate limits min/max, pitch torque limits min/max, ratio of pitch system (pitch drive gear box and pitch bearing mesh), gear box efficiency, rotational inertia of pitch drive, all pitch bearing friction parameters, blade pitching inertia

q) Requirements for the evaluation and presentation of the calculation results are defined in Appendix 4.B.

4.1.3 Design methods

(1) This Guideline requires the determination of design loads. If these are determined by computation, a structural dynamics model shall be used. This model shall be used to determine the loads over a range of wind speeds, with due consideration of the aeroelastic coupling. Here, as a minimum, the turbulence conditions and other extreme wind conditions, as defined in Sections 4.2 and 4.3, shall be applied. All relevant combinations of external conditions and design situations shall be analysed. A minimum set of such combinations is defined as load cases in Section 4.3.3.

(2) Verification of the adequacy of the design shall be made by calculation and/or by measurements. If measurement results are used in this verification, the environmental conditions prevailing during the test shall be shown to reflect the characteristic values and design situations defined in this Guideline. The selection of measurement conditions, including the test loads, shall take account of the relevant partial safety factors to be applied, and shall be agreed with GL.

(3) For the definition of the loads, the meteorological and orographical data relevant for the installation site shall apply. Special attention shall be paid to extreme locations, such as polar regions, high mountains, deserts and areas in which tropical cyclones may occur (see Section 4.4). If the actual operational conditions are not sufficiently known, then the wind turbine can be designed according to one of the wind turbine classes specified in Section 4.2.2 and the data described below. Before erection of the turbine, however, it shall be ensured that the design conditions at the site adequately cover the prevailing external conditions. For turbines erected within a wind farm, the mutual influence shall be taken into account. This manifests itself in increased turbulence and non-uniform inflow (see Section 4.4.6).

4.1.4 Safety classes

(1) A wind turbine shall be designed according to one of the following two safety classes:

- the normal safety class which applies when a failure results in the risk of personal injury or economic and social consequences;
- the special safety class which applies when the safety requirements are determined by local regulations and/or the safety requirements are agreed between the manufacturer and the customer.

(2) Partial safety factors for a wind turbine of the normal safety class are specified in Section 4.3.5 of this Guideline. Partial safety factors for wind turbines of the special safety class require prior agreement. A wind turbine designed according to the special safety class is a “class S” turbine, as defined in Section 4.2.2.

4.2 External Conditions

4.2.1 General

(1) The external conditions described in the present section shall be considered as a minimum for the design of a wind turbine.

(2) Wind turbines are subjected to environmental and electrical conditions which may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, the environmental, electrical and soil parameters shall be taken into account in the design, and shall be explicitly stated in the design documentation.

(3) The environmental conditions are further divided into wind conditions and other environmental conditions. The electrical conditions refer to the grid conditions. For the design of the wind turbine foundations and the determination of the pertinent loads, the soil properties shall be taken into account (see Section 6.7.6).

(4) Each type of external condition may be subdivided into a normal and an extreme external condition. The normal external conditions generally concern long-term structural loading and operating conditions, while the extreme external conditions represent the rare but potentially critical external design conditions. The design load cases consist of a combination of these external conditions with the wind turbine operational modes.

(5) The normal and extreme conditions which are to be considered in design according to wind turbine classes are prescribed in the following sections.

4.2.2 Wind turbine classes

(1) The external conditions to be considered in design are dependent on the intended site or site type for a wind turbine installation. Wind turbine classes are defined in terms of wind speed and turbulence parameters. In addition, the external conditions are also defined together with the wind turbine class. The intention of the classes is to cover most applications. The values of wind speed and turbulence parameters are intended to represent the characteristic values of many different sites and do not give a precise representation of any specific site. The goal is to achieve wind turbine classification with clearly varying degrees of robustness governed by the wind speed and turbulence parameters. Table 4.2.1 specifies the basic parameters which define the wind turbine classes.

(2) A plant designed for the wind turbine class with a reference wind speed V_{ref} is so designed that it can withstand the environmental conditions in which the 10-min mean of the extreme wind speed with a recurrence period of 50 years at hub height is equal to or less than V_{ref}.

Table 4.2.1 Basic parameters for wind turbine classes

Wind turbine class	I	II	III	S
– V_{ref} [m/s]	50	42.5	37.5	Values to be specified by the manufacturer
– V_{ave} [m/s]	10	8.5	7.5	
– A I_{15} (-)	0.18	0.18	0.18	
– a (-)	2	2	2	
– B I_{15} (-)	0.16	0.16	0.16	
– a (-)	3	3	3	

(3) The mean wind speed V_{ave} is a statistical mean of the instantaneous value of the wind speed, averaged over a certain period ranging from a few seconds to many years. In this Guideline, the annual average of the wind speed over many years is meant. This value is used in the Weibull or Rayleigh functions which represent the wind speed distribution (see Section 4.2.3.1.1).

(4) In cases where a special design (e.g. special wind conditions or other external conditions, or a special safety class) is necessary, a further wind turbine class, “class S”, is defined (see Section 4.1.4). The design values for the wind turbine class S shall be chosen and specified in the design documentation. It shall then be ensured that the design conditions adequately cover the prevailing external conditions at the site (Section 4.1.3). For such special designs, the values chosen for the design conditions shall reflect a more severe environment than anticipated for the use of the wind turbine.

(5) The values apply at hub height, where:

V_{ref} = reference wind speed

V_{ave} = annual average wind speed over many years at hub height

A = category for higher turbulence intensity values

B = category for lower turbulence intensity values

I_{15} = characteristic value of the turbulence intensity at 15 m/s

a = slope parameter to be used in equation 4.2.5

(6) In addition to these basic parameters, several other parameters are required to specify completely the external conditions used in wind turbine design. In the case of the wind turbine classes I_A through III_B, later referred to as standard wind turbine classes, the values of these additional parameters are specified in Sections 4.2.3, 4.2.4 und 4.2.5.

(7) The design lifetime shall be at least 20 years.

(8) For the wind turbine class S, the manufacturer shall in the design documentation describe the models used and the values of essential design parameters. Where the models in Section 4.2 are adopted, statement of the values of the parameters will be sufficient. The design documentation of wind turbine class S shall at least contain the information listed in Appendix 4.D.

4.2.3 Wind conditions

(1) A wind turbine shall be designed to withstand safely the wind conditions defined by the selected wind turbine class.

(2) The design values of the wind conditions shall be clearly specified in the design documentation.

(3) The wind regime for load and safety considerations is divided into the normal wind conditions, which will occur frequently during normal operation of a wind turbine, and the extreme wind conditions, which are defined as having a 1-year or 50-year recurrence period.

(4) In all load cases, the influence of an inclination of the mean flow with respect to the horizontal plane of up to 8° shall be considered. The flow inclination (upflow) angle may be assumed to be invariant with height.

4.2.3.1 Normal wind conditions

4.2.3.1.1 Wind speed distribution

(1) The wind speed distribution at the site is significant for the wind turbine design, because it determines the frequency of occurrence of the individual load components. In the following, the Weibull distribution (equation 4.2.1) and the Rayleigh distribution (equation 4.2.2) are given. For design in the standard wind turbine classes, the Rayleigh distribution (equation 4.2.2) shall be taken for the load calculations.

$$P_W(V_{hub}) = 1 - \exp\left[-(V_{hub}/C)^k\right] \qquad (4.2.1)$$

$$P_R(V_{hub}) = 1 - \exp\left[-\pi(V_{hub}/2V_{ave})^2\right] \qquad (4.2.2)$$

$$\text{with } V_{ave} = \begin{cases} C\dfrac{\sqrt{\pi}}{2}, \; if\ k = 2 \\ C\,\Gamma\left(1+\dfrac{1}{k}\right) \end{cases} \qquad (4.2.3)$$

where:

$P_W(V_{hub})$ = Weibull probability distribution: cumulative probability function, i.e. the probability that $V < V_{\mathrm{hub}}$ [-]

$P_R(V_{hub})$ = Rayleigh probability function: cumulative probability function, i.e. the probability that $V < V_{hub}$ [-]

V_{hub} = 10-min mean of the wind speed at hub height [m/s]

V_{ave} = annual average wind speed at hub height [m/s]

C = scale parameter of the Weibull function [m/s]

k = shape parameter of the Weibull function. For design in the standard wind turbine class, the value k = 2 shall be taken [-]

Γ = gamma function [-]

(2) C and k can be derived from real data. The Rayleigh function is identical to the Weibull function if $k = 2$ is selected and C and V_{ave} satisfy the condition given in equation 4.2.3 for $k = 2$.

(3) The distribution functions indicate the cumulative probability that the wind speed is less than V_{hub} . From this, it obtains that $(P\{V_1\} - P\{V_2\})$ specifies the proportion of the time in which the wind speed varies within the limits V_1 and V_2 . On derivation of the distribution functions, the corresponding probability density functions are obtained.

4.2.3.1.2 Normal wind profile model (NWP)

The wind profile $V(z)$ denotes the average wind speed as a function of height z above the ground. In the case of standard wind turbine classes, the normal wind speed profile shall be assumed to be given by the power law:

$$V(z) = V_{hub}\left(z / z_{hub}\right)^{\alpha} \tag{4.2.4}$$

where:

$V(z)$ = wind speed at the height z [m/s]

z = height above ground [m]

z_{hub} = hub height above ground [m]

α = power law exponent [-]

The power law exponent α shall be assumed to be 0.2.

The assumed wind profile is used to define the average vertical wind shear across the rotor swept area.

4.2.3.1.3 Normal turbulence model (NTM)

(1) The turbulence of the wind is represented by energy carried along by the turbulence eddies. Its distribution over frequencies – represented by power spectra and coherence functions – can generally be regarded as an adequate representation of the turbulence over a period of approx. 10 minutes that is in the spirit of this Guideline. The characterization of the natural turbulence of the wind by statistic parameters for the relatively short period in which the spectrum remains unchanged leads inter alia to the following parameters:

- mean value of the wind speed
- turbulence intensity
- integral length scales

(2) Standard combinations of external parameters, such as the fetch of the wind, roughness length, mean wind speed etc., with power spectra and coherence functions of the wind speed are considered as basically acceptable starting points for a description of the turbulence.

(3) The values of the turbulence intensity shall be taken at hub height. For other heights, it may be assumed that the standard deviation of the wind speed remains constant, whilst the wind speed varies with height according to Section 4.2.3.1.2, with the turbulence intensity thus also changing. Particular attention shall be paid to the random change in wind speed over the rotor swept area. This aspect, as well as deterministic wind speed changes, generates together with the rotation of the rotor the effect of "rotational sampling" (i.e. repeated passing through partial gusts). This effect can exert a considerable influence on the fatigue strength. In general, three-dimensional turbulence models, which consider not only the longitudinal but also the transversal and lateral wind speed components, shall be used.

(4) The site-specific influence of the orography and topography on the turbulence intensity actually prevailing shall be taken into account. The change in the turbulence intensity, the mean value of the wind speed as well as the integral length scale for erection in a wind farm (mutual influence of the turbines) shall be considered (see Section 4.4.6).

(5) For the standard wind turbine classes, the power spectral densities of the random wind velocity vector field, whether used explicitly in the model or not, shall satisfy the following requirements:

a) The characteristic value for the standard deviation of the longitudinal wind velocity component at hub height shall be given by:

$$\sigma_1 = I_{15}\,(15\,m/s + aV_{hub})\,/(a+1) \tag{4.2.5}$$

where:

σ_1 = standard deviation of the longitudinal wind speed at hub height [m/s]

This standard deviation shall be assumed to be invariant with height.

Note:

To perform the calculations of load cases in addition to those specified in Tables 4.3.1 and 4.3.2, it may be appropriate to use different percentile values. Such percentile values shall be determined by adding the following value to equation 4.2.5:

$$\Delta\sigma_1 = (x-1)(2m/s)\,I_{15} \qquad (4.2.6)$$

where x *is determined from the normal probability distribution function. For example,* x *= 1.64 for a 95th percentile value.*

Values for I_{15} and a are given in Table 4.2.1. The standard deviation of the wind speed σ_1 and of the turbulence intensity σ_1 / V_{hub} are shown in Fig. 4.2.1 as a function of wind speed for the specified values of I_{15} and a.

b) Towards the high frequency end of the inertial sub-range, the power spectral density of the longitudinal component of the turbulence $S_1(f)$ shall asymptotically approach the form:

$$S_1(f) = 0.05\,(\sigma_1)^2\left(\Lambda_1/V_{hub}\right)^{-2/3} f^{-5/3} \qquad (4.2.7)$$

where:

$S_1(f)$ = power spectral density [m^2/s^2]

Λ_1 = turbulence scale parameter, defined as the wavelength at which the dimensionless longitudinal power spectral density $f\,S_1(f)/\sigma_1^2$ equals 0.05 [m]

f = frequency [s^{-1}]

The turbulence scale parameter Λ_1 shall be given by:

$$\Lambda_1 = \begin{cases} 0.7 z_{\text{hub}} & \text{for } z_{\text{hub}} < 60\text{m} \\ 42\text{m} & \text{for } z_{\text{hub}} \geq 60\text{m} \end{cases} \qquad (4.2.8)$$

(6) Specifications for stochastic turbulence models are given in [4.4], [4.5] and [4.8].

(7) The following general requirements shall be observed for load calculations with turbulent wind:

- The simulation period of each simulation run with the normal turbulence model (NTM) shall be at least 10 minutes per simulation run.
- In the fatigue loading calculation, each simulation run shall be performed with a different initial value (“seed”) for producing the turbulent wind field.
- Three-dimensional turbulence fields shall be used.
- The resolution of the turbulent wind fields shall be adequate. A minimum of at least 10 x 10 points (depending on diameter) is recommended. However, the grid spacing should be less than 10 m.
- For the evaluation of tower section loads, the wind field shall cover the entire plant (rotor and tower), or a substitute model may be used after consultation with GL.

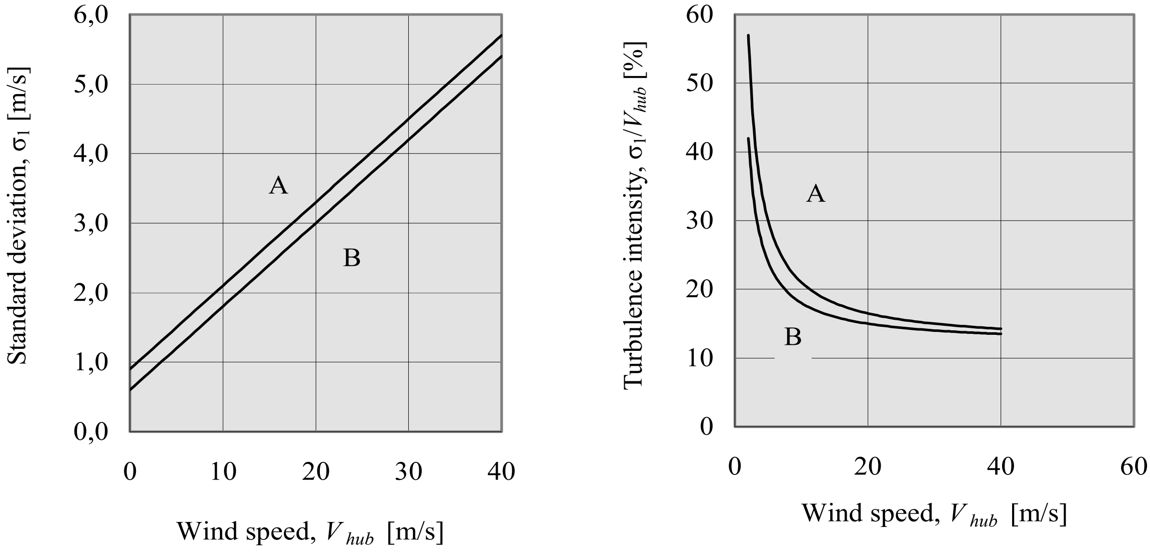


Fig. 4.2.1 Characteristic wind turbulence

4.2.3.2 Extreme wind conditions

The extreme wind conditions are used to determine the extreme wind loads acting on wind turbines. These conditions include peak wind speeds due to storms and rapid changes in wind speed and direction. These extreme conditions include the potential effects of wind turbulence, with the exception of the EWM (see Section 4.2.3.2.1), so that only the deterministic effects need to be considered in the design calculations.

4.2.3.2.1 Extreme wind speed model (EWM)

(1) The EWM can be either a steady or a turbulent wind model. The wind models are based on the reference wind speed V_{ref} and a certain standard deviation σ_I.

(2) For the steady extreme wind model, the 50-year extreme wind speed V_{e50} and the one-year extreme wind speed V_{e1} shall be based on the reference wind speed V_{ref}. For the standard wind turbine classes, V_{e50} and V_{e1} shall be computed as a function of the height z using the following equations:

$$V_{e50}(z) = 1.4\, V_{ref}(z/z_{hub})^{0,11} \qquad (4.2.9)$$

$$V_{e1}(z) = 0.8\, V_{e50}\,(z) \qquad (4.2.10)$$

where:

$V_{eN}(z)$ = the expected extreme wind speed (averaged over 3 s), with a recurrence period of N years and V_{e1} and V_{e50} representing 1 and 50 years, respectively. The EWM is applied with a steady wind model.

V_{ref} = reference wind speed according to Table 4.2.1

(3) For the turbulent extreme wind model, the 10-minute mean of the wind speed is given as a function of the height z with a recurrence period of 50 years or 1 year by the following equations:

$$V_{50}\,(z) = V_{ref}\,(z/z_{hub})^{0,11} \qquad (4.2.11)$$

$$V_1(z) = 0.8\, V_{ref}(z\,/\,z_{hub})^{0.11} \qquad (4.2.12)$$

where:

$V_N(z)$ = the expected extreme wind speed (averaged over 10 minutes), with a recurrence period of N years and V_1 and V_{50} representing 1 and 50 years, respectively. The EWM is applied with a turbulent wind model.

(4) For the turbulent extreme wind model, the mean wind speed at hub height V_{hub} shall be taken as V_{ref} or $0.8 \cdot V_{ref}$. The turbulence model to be applied shall correspond to the turbulence model NTM (see Section 4.2.3.1.3), with a standard deviation of $\sigma_I = 0.11 \cdot V_{\mathrm{hub}}$.

(5) The following general requirements shall be observed for load calculations with the EWM:

- The simulation period of each simulation run with the turbulent EWM shall be at least 10 minutes per simulation run.
- In the case of load simulations with the turbulent extreme wind model, the notes in Section 4.B.1 shall be observed with regard to calculation and evaluation of the loads.
- In the case of load simulations with the turbulent extreme wind model, the wind fields used shall be based on different initial values (seeds) for generating the wind fields.
- If tower section loads are evaluated, the wind field shall cover the entire plant (rotor and tower), or a substitute model may be used after consultation with GL.

Note (generally valid for the EWM):

Sometimes, the extreme wind speeds are obtained for other averaging periods or other exceedance probabilities. If no other proven data are available, the wind speed may be decreased by 4 % for conversion of the wind with an exceedance probability of once in 100 years to once in 50 years. Similarly, the wind speed may be decreased by 3 % for conversion of the 3-second gust to the 5-second gust. For conversion of 60-min mean values to 10-min mean values, the wind speed shall be increased by 10 %.

4.2.3.2.2 Extreme operating gust (EOG)

(1) The gust magnitude V_{gustN} at hub height for a recurrence period of N years shall be calculated for the standard wind turbine classes by the following relationship:

$$V_{gustN} = \beta\, \sigma_1\, B \qquad (4.2.13)$$

where:

V_{gustN} = maximum value of the wind speed for the extreme operating gust, with an expected recurrence period of N years [m/s]

σ_1 = standard deviation, according to equation 4.2.5

β = 4.8 for $N = 1$

β = 6.4 for $N = 50$

B = Size reduction factor

(2) In order to consider the size of the structure and the wind speed coherence for deterministic effects, a size reduction factor B is defined:

$$B = \frac{1}{1 + 0.2\left(\frac{D}{\Lambda_1}\right)} \tag{4.2.14}$$

Λ_1 = turbulence scale parameter, according to equation 4.2.8

D = rotor diameter [m]

(3) The wind speed shall be defined for a recurrence period of N years by equation 4.2.15, where:

$V(z)$ = see equation 4.2.4

T = 10.5 s for $N = 1$

T = 14.0 s for $N = 50$

(4) An example of an extreme operating gust for a recurrence period of 1 year is given in Fig. 4.2.2 for $V_{hub} = 25$ m/s and turbulence category A.

4.2.3.2.3 Extreme direction change (EDC)

(1) The extreme direction change magnitude θ_{eN} for a recurrence period of N years shall be calculated using equation 4.2.16,

where:

θ_{eN} = extreme direction change, with a recurrence period of N years, limited to the range ±180°

β = 4.8 for $N = 1$

β = 6.4 for $N = 50$

B = size reduction factor, according to equation 4.2.14

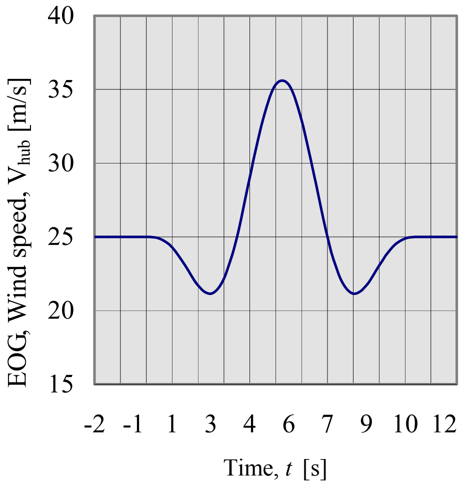


Fig. 4.2.2 **Example of an extreme operating gust (N = 1, category A, D = 42 m, z_{hub} = 30 m, V_{hub} = 25 m/s)**

$$V(z,t) = \begin{cases} V(z) - 0.37\,V_{gustN}\sin(3\pi t/T)(1-\cos(2\pi t/T)) & \text{for } 0 \le t \le T \\ V(z) & \text{for } t < 0 \text{ and } t > T \end{cases} \tag{4.2.15}$$

$$\theta_{eN} = \pm\beta\arctan\left(\frac{\sigma_1}{V_{hub}}B\right) \tag{4.2.16}$$

$$\theta_N(t) = \begin{cases} 0 & \mathit{for}\ t < 0 \\ 0.5\,\theta_{eN}(1-\cos(\pi t/T)) & \mathit{for}\ 0 \le t \le T \\ \theta_{eN} & \mathit{for}\ t > T \end{cases} \tag{4.2.17}$$

$$V(z,t) = \begin{cases} V(z) & \mathit{for}\ t < 0 \\ V(z) + 0.5\,V_{cg}(1-\cos(\pi t/T)) & \mathit{for}\ 0 \le t \le T \\ V(z) + V_{cg} & \mathit{for}\ t > T \end{cases} \tag{4.2.18}$$

(2) The extreme direction change for a recurrence period of N years $\theta_N(t)$ is given by equation 4.2.17.

(3) Here $T = 6$ s is the duration of the extreme direction change transient. The sign shall be chosen so that the worst transient loading occurs. At the end of the direction change transient, the wind direction shall be assumed to remain unchanged. Furthermore, the wind speed shall be assumed to follow the normal wind profile model of Section 4.2.3.1.2.

(4) As an example, the extreme direction change with a recurrence period of 50 years, turbulence category A and V_{hub} = 25 m/s is shown in Figs. 4.2.3 and 4.2.4 as a function of V_{hub} and as a function of time for V_{hub} = 25 m/s.

4.2.3.2.4 Extreme coherent gust (ECG)

(1) For designs for the standard wind turbine classes, an extreme coherent gust with a magnitude of:

$$V_{cg} = 15 \text{ m/s}$$

shall be assumed. The wind speed is defined by the relations given in equation 4.2.18.

(2) Here T = 10 s is the rise time and $V(z)$ the wind speed given in Section 4.2.3.1.2 “Normal wind profile model (NWP)”. The extreme coherent gust is illustrated in Fig. 4.2.5 for V_{hub} = 25 m/s.

4.2.3.2.5 Extreme coherent gust with direction change (ECD)

(1) In this case, the rise in wind speed (described by ECG; see Fig. 4.2.5) shall be assumed to occur simultaneously with the direction change θ_{cg}, where θ_{cg} is defined by the relations in the following equation:

$$\theta_{cg}\left(V_{hub}\right) = \begin{cases} 180^\circ & for\ V_{hub} < 4m/s \\ \dfrac{720^\circ\, m/s}{V_{hub}} & for\ 4m/s \le V_{hub} \le V_{ref} \end{cases} \qquad (4.2.19)$$

(2) The direction change θ_{cg} as a function of V_{hub} and as a function of time for V_{hub} = 25 m/s is shown in Figs. 4.2.6 and 4.2.7 respectively.

(3) The simultaneous direction change is given by equation 4.2.20.

(4) Here T = 10 s is the rise time. The normal wind profile model as specified in equation 4.2.4 shall be used.

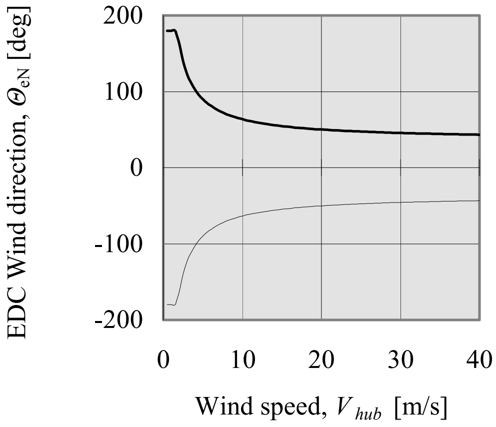


Fig. 4.2.3 **Example of the magnitude of the extreme direction change (N = 50, category A, D = 42 m, z_{hub} = 30 m)**

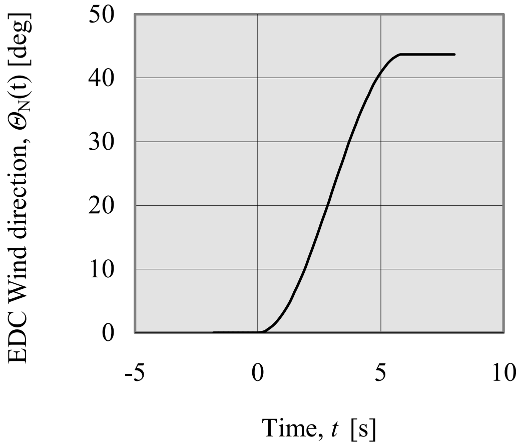


Fig. 4.2.4 **Example of extreme direction change (N = 50, category A, V_{hub} = 25 m/s)**

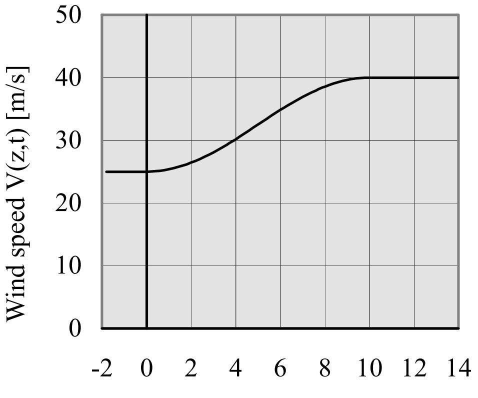


Fig. 4.2.5 **Example of an extreme coherent gust (V_{hub} = 25 m/s) (ECG)**

$$\theta(t)=\begin{cases}0^0 & \text{for } t<0\\ \pm 0.5\,\theta_{cg}(1-\cos(\pi\, t/T)) & \text{for } 0\le t\le T\\ \pm\theta_{cg} & \text{for } t>T\end{cases}\qquad(4.2.20)$$

$$V(z,t)=\begin{cases}V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha}\pm\left(\dfrac{z-z_{hub}}{D}\right)\left(2.5m/s+0.2\beta\sigma_1\left(\dfrac{D}{\Lambda_1}\right)^{1/4}\right)\left(1-\cos\left(\dfrac{2\pi t}{T}\right)\right) & \text{for } 0\le t\le T\\ V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} & \text{for } t<0 \text{ and } t>T\end{cases}\qquad(4.2.21)$$

$$V(y,z,t)=\begin{cases}V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha}\pm\left(\dfrac{y}{D}\right)\left(2.5m/s+0.2\beta\sigma_1\left(\dfrac{D}{\Lambda_1}\right)^{1/4}\right)\left(1-\cos\left(\dfrac{2\pi t}{T}\right)\right) & \text{for } 0\le t\le T\\ V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} & \text{for } t<0 \text{ and } t>T\end{cases}\qquad(4.2.22)$$

4.2.3.2.6 Extreme wind shear (EWS)

(1) The extreme wind shear with a recurrence period of 50 years shall be considered by using the following two wind speed transients:

- for transient vertical shear, as defined in equation 4.2.21, and
- for transient horizontal shear, as defined in equation 4.2.22.

where:

α = 0.2

β = 6.4

T = 12 s

Λ_1 = turbulence scale parameter, according to equation 4.2.8

D = rotor diameter

(2) The sign for the wind shear transients shall be chosen so that the most unfavourable transient loading occurs. The two extreme wind shears are considered independently of each other and are therefore not applied simultaneously. As an example, the extreme positive vertical wind shear is illustrated in Fig. 4.2.8, which shows the wind profile before onset of the extreme event (*t* = 0 s). Fig 4.2.9 shows the wind speeds at the top and the bottom of the rotor swept area to illustrate the time development of the shear. In both figures, turbulence category A and V_{hub} = 25 m/s, z_{hub} = 30 m and rotor diameter *D* = 42 m are assumed.

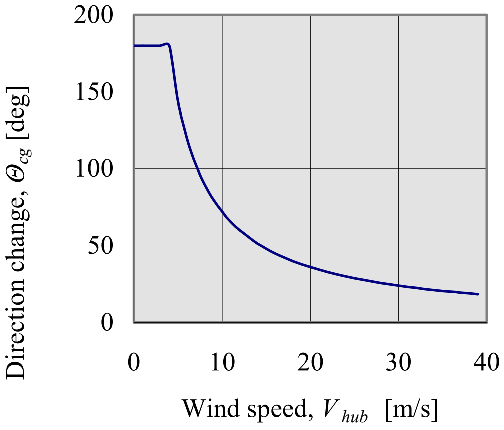


Fig. 4.2.6 **Direction change for ECD**

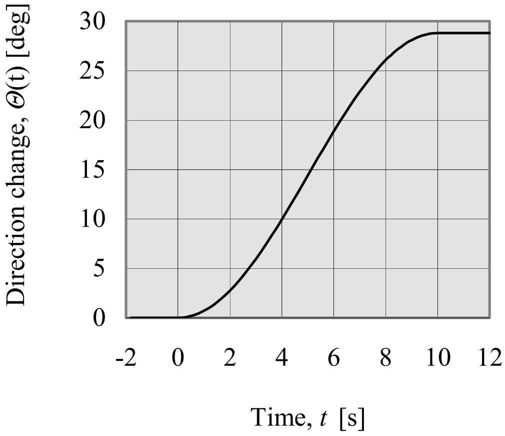


Fig. 4.2.7 **Direction change for V_{hub} = 25 m/s**

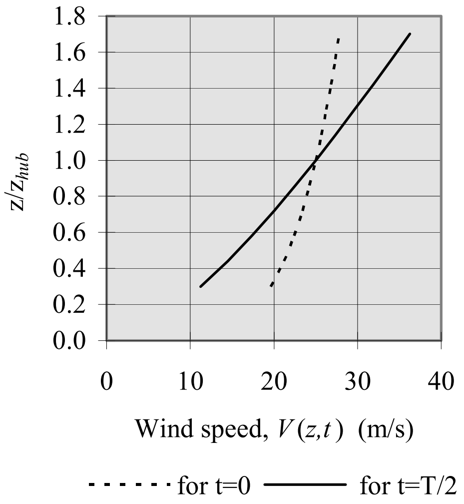


Fig. 4.2.8 **Extreme positive vertical wind shear, wind profile before onset (t = 0, dashed line) and at maximum shear (t = 6 s, full line) (N = 50, turbulence category A, z_{hub} = 30 m, V_{hub} = 25 m/s, D = 42 m)**

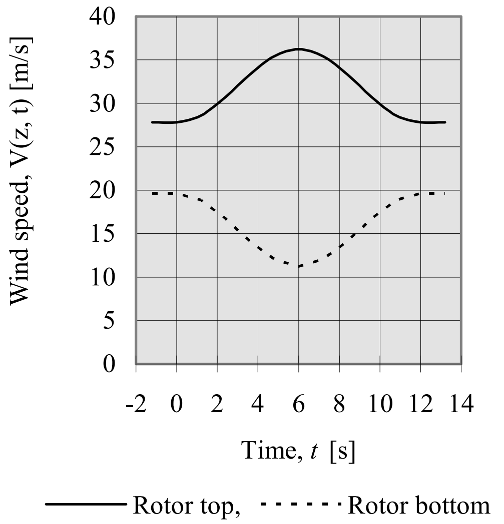


Fig. 4.2.9 **Wind speeds at the top and bottom of the rotor swept area (assumptions as in Fig. 4.2.8)**

4.2.4 Other environmental conditions

(1) Environmental (climatic) conditions other than wind can affect the integrity and safety of the wind turbine, by thermal, photochemical, corrosive, mechanical, electrical or other physical action. Moreover, combinations of the climatic parameters given may increase their effect.

(2) At least the following other environmental conditions shall be taken into account and the action taken stated in the design documentation:

- normal and extreme temperature ranges
- humidity
- air density
- solar radiation
- rain, hail, snow and ice formation
- chemically active substances
- mechanically active particles
- lightning
- earthquakes
- salinity

(3) The climatic conditions for the design shall be defined in terms of representative values or by the limits of the variable conditions. The probability of simultaneous occurrence of the climatic conditions shall be taken into account when the design values are selected.

(4) Variations in the climatic conditions within the normal limits which correspond to a one-year recurrence period shall not interfere with the designed normal operation of a wind turbine.

4.2.4.1 Other normal environmental conditions

(1) Other normal environmental condition values which shall be taken into account are:

- Wind turbines shall be designed for an ambient temperature range of –20 °C to +50 °C. As variations of the constant temperature components, ±35 K in relation to an installation temperature of +15 °C shall be assumed. Operation shall be possible at ambient temperatures from –10 °C to +40 °C.
- relative humidity of up to 100 %
- atmospheric content equivalent to that of a non-polluted inland atmosphere
- solar radiation intensity of 1,000 W/m^2
- air density of 1.225 kg/m^3

(2) When additional external condition parameters are specified by the designer, these parameters and their values shall be stated in the design documentation.

4.2.4.2 Other extreme environmental conditions

Other extreme environmental conditions which shall be considered are temperature, lightning, ice and earthquakes.

4.2.4.2.1 Lightning

The provisions set out in Section 8.9 "Lighting protection" to safeguard against lightning strikes may be regarded as adequate for the standard wind turbine classes.

4.2.4.2.2 Ice

(1) For non-rotating parts of the wind turbine, ice formation with a thickness of 30 mm on all sides shall be assumed for surfaces exposed to the weather. The density of the ice shall be taken as $\rho_E = 700$ kg/m^3. In the case of operating conditions in which the rotor is at standstill, the rotor blades shall also be verified for this degree of ice formation on all sides.

(2) With the rotor rotating, the conditions "ice formation on all rotor blades" and "ice formation on all rotor blades except one" shall be investigated. The mass distribution (mass / unit length) shall be assumed at the leading edge. It increases linearly from zero in the rotor axis to the value μ_E at half the radius, and then remains constant up to the outermost radius. The value μ_E is calculated as follows:

$$\mu_E = \rho_E \cdot k \cdot c_{\min}(c_{\max} + c_{\min}) \qquad (4.2.23)$$

where:

μ_E = mass distribution on the leading edge of the rotor blade at half the rotor radius [kg/m]

ρ_E = density of the ice (700 kg/m3)

k = 0.00675 + 0.3 exp (-0.32 R/R$_1$) [-]

R = rotor radius [m]

R_1 = 1 m

c_{max} = maximum chord length [m]

c_{min} = chord length at the blade tip, linearly extrapolated from the blade contour [m]

4.2.4.2.3 Earthquakes

The loading caused by earthquakes shall be taken into account in areas at risk from earthquakes (see Section 4.3.3.9 (5).

4.2.5 Electrical power network conditions

The normal conditions to be considered at the wind turbine terminals are listed in this section. Normal electrical power network conditions apply when the following parameters fall within the ranges stated below.

- voltage: nominal value ±10 %
- frequency: nominal value ±2 %
- voltage imbalance: The ratio of the negative-sequence component of voltage to the positive-sequence component shall not exceed 2 %.
- grid loss: Electrical network outages shall be assumed to occur 20 times per year (see also Sections 2.2.2.12 and 2.2.2.13).

4.3 Calculation of the Loads

4.3.1 General

(1) The structural design of wind turbines shall be based on verification of the structural integrity of the load-carrying components. The ultimate and fatigue strength of structural members shall be verified by calculations and/or tests to demonstrate the structural integrity of a wind turbine with the appropriate safety level.

(2) For the structural design, Section 1.3 shall be observed.

(3) An acceptable safety level shall be ensured. Calculations and/or tests shall be carried out to demonstrate that the design loading will not exceed the relevant design resistance.

(4) Calculations shall be performed using appropriate methods. Descriptions of the calculation methods shall be provided in the design documentation. These descriptions shall include evidence of the validity of the calculation methods or references to suitable verification studies. The load level in any test shall adequately reflect the partial safety factors in the corresponding calculation.

4.3.2 Loads

The loads described in Sections 4.3.2.1 to 4.3.2.4 shall be considered for the design calculations. Prototype tests may also be used as a substitute for load calculation. The extent of measurements shall be agreed with GL. The measurements shall be carried out by an accredited institute.

4.3.2.1 Inertial and gravitational loads

Inertial and gravitational loads are static and dynamic loads acting on wind turbines, resulting from vibration, rotation, gravity and seismic activity.

4.3.2.2 Aerodynamic loads

(1) Aerodynamic loads are static and dynamic loads which are caused by the airflow and its interaction with the stationary and moving parts of wind turbines.

(2) The aerodynamic load is dependent upon the rotational speed of the rotor, the average wind speed across the rotor plane, the turbulence intensity, the density of the air, and the aerodynamic shapes of the wind turbine components and their interactive effects, including the aeroelastic effects.

4.3.2.3 Operational loads

(1) Operational loads result from the operation and control of wind turbines. They shall be assigned to several categories. These are the control of rotor speed and the torque control by pitching of blades or other aerodynamic devices. Other operational loads are the mechanical braking and transient loads arising during the starting and stopping of the rotor, connection and disconnection of the generator, and yaw movements.

(2) The control of the wind turbine shall be considered according to Section 4.5.

4.3.2.4 Other loads

Other loads (such as wake loads, impact loads, ice loads etc.) may occur and shall be included where appropriate. Special conditions of the installation site shall be considered (see Section 4.4).

4.3.3 Design situations and load cases

(1) This section describes the construction of design load cases and specifies a minimum number to be considered.

(2) For design purposes, the life of a wind turbine can be represented by a set of design situations covering the most significant conditions which the wind turbine may experience.

(3) The load cases shall be determined from the combination of specific erection, maintenance, and operational modes or design situations with the external conditions. All relevant load cases with a reasonable probability of occurrence shall be considered in conjunction with the behaviour of the control and safety systems.

(4) In general, the design load cases used to determine the structural integrity of a wind turbine may be calculated from the following combinations:

- normal design situations and normal external conditions
- normal design situations and extreme external conditions

- fault design situations and appropriate external conditions
- design situations for transportation, installation and maintenance, and the appropriate external conditions

Note:

Normal external conditions are assigned a recurrence period of 1 year, whereas extreme external conditions are assigned a recurrence period of 50 years as a rule.

(5) If any correlation exists between an extreme external condition and a fault situation, a realistic combination of the two shall be considered as a design load case.

(6) The design load cases are taken into account in two groups. The design load cases associated with both groups shall verify the structural integrity of the wind turbine components for the respective design situations. The design situations are represented by a combination of wind, electrical and other external conditions in the normal rotational speed range.

(7) The first group of design load cases as stated in Table 4.3.1 considers design situations forming the minimum extent to be considered for Type Certification.

(8) The second group of design load cases as stated in Table 4.3.2 accounts for extended design situations of special applications, site design conditions and, where applicable, wind farm arrangement, also within a Site-specific Design Assessment (Section 1.2.3.4). Additionally, they may extent the environmental conditions described in Section 4.2 for all wind classes. For Type Certification, these design load cases are not mandatory, but may be chosen for the verification of the wind turbine to complement the applicability in the respective design situations.

(9) For each design situation in the normal rotational speed range, several design load cases shall be considered to verify the structural integrity of wind turbine components. As a minimum, the design load cases in Table 4.3.1 shall be considered. This table specifies the design load cases for each design situation through the description of the wind, electrical and other external conditions.

(10) Other design load cases relevant for safety shall be considered in consultation with GL, if required by the specific wind turbine design or by the control concept.

(11) For each design load case, the appropriate type of analysis is stated by “F” and “U” in Table 4.3.1 and Table 4.3.2. F refers to analysis of fatigue loads, to be used in the assessment of fatigue strength. U refers to the analysis of ultimate loads, such as analysis of exceeding the maximum material strength, analysis of tip deflection, and stability analysis.

(12) The design situations indicated with U are classified further as normal (N), abnormal (A), or transport and erection (T). Normal design situations are expected to occur frequently within the lifetime of a turbine. The turbine is in a normal state or may have experienced minor malfunctions or abnormalities. Abnormal design situations are less likely to occur. They usually correspond to design situations with more severe malfunctions, e.g. faults in the safety system. The type of design situation (N, A, or T) determines the partial safety factor γ_F to be applied to the ultimate loads. These factors are given in Table 4.3.3.

(13) In the definition of the design load cases, reference is made to the wind conditions described in Section 4.2. When a wind speed range is indicated in Table 4.3.1 and, if applicable, Table 4.3.2, the wind speeds leading to the most adverse condition for wind turbine design shall be considered. For the analysis of the fatigue strength (F), the range may be divided into a number of sub-ranges; each sub-range shall be allocated the corresponding proportion of the turbine’s operating life.

(14) If the use of a mechanical brake by the control or safety system is prescribed in a load case, both the minimum and the maximum braking torque shall be taken into account. The occurrence of each braking torque in the range between the minimum and the maximum braking torque is regarded as a normal condition and not as a fault. The suitability of the brakes (minimum braking torque) shall be verified for load case DLC 8.1. The definitions of the minimum and the maximum braking torques are given in Section 7.5.

Table 4.3.1 Design load cases

Design situation	DLC	Wind conditions[1]	Other conditions	Type of analysis	Partial safety factors
1. Power production	1.1	NTM $V_{in} \le V_{hub} \le V_{out}$		F / U	* / N
	1.2	omitted			
	1.3	ECD $V_{in} \le V_{hub} \le V_r$		U	N
	1.4	NWP $V_{in} \le V_{hub} \le V_{out}$	Grid loss	F / U	* / N
	1.5	EOG$_1$ $V_{in} \le V_{hub} \le V_{out}$	Grid loss	U	N
	1.6	EOG$_{50}$ $V_{in} \le V_{hub} \le V_{out}$		U	N
	1.7	EWS $V_{in} \le V_{hub} \le V_{out}$		U	N
	1.8	NWP $V_{in} \le V_{hub} \le V_{out}$	Ice formation	F / U	* / N
2. Power production plus occurrence of fault	2.1	NWP $V_{in} \le V_{hub} \le V_{out}$	Fault in the control system	F / U	* / N
	2.2	NWP $V_{in} \le V_{hub} \le V_{out}$	Fault in the safety system or preceding internal electrical fault	F / U	* / A
3. Start-up	3.1	NWP $V_{in} \le V_{hub} \le V_{out}$		F / U	* / N
	3.2	EOG$_1$ $V_{in} \le V_{hub} \le V_{out}$		U	N
4. Normal shut-down	4.1	NWP $V_{in} \le V_{hub} \le V_{out}$		F / U	* / N
	4.2	EOG$_1$ $V_{in} \le V_{hub} \le V_{out}$		U	N
5. Emergency shut-down	5.1	NWP $V_{in} \le V_{hub} \le V_{out}$		U	N
6. Parked (standstill or idling)	6.1	EWM Recurrence period 50 years		U	N
	6.2	EWM Recurrence period 50 years	Grid loss	U	A
	6.3	EWM Recurrence period 1 year	Extreme oblique inflow	U	N
	6.4	NTM $V_{hub} < V_{in}$ *and* $V_{out} < V_{hub} < 0.8\ V_{ref}$		F / U	* / N
7. Parked plus fault conditions	7.1	EWM Recurrence period 1 year		U	A
8. Transport, erection, maintenance and repair	8.1	EOG$_1$ $V_{hub} = V_T$ or NWP $V_{hub} = max\ (EOG_1$ *based on* $V_T)$	To be specified by the manufacturer	U	T
	8.2	EWM Recurrence period 1 year	Locked state	U	A

* Partial safety factor for fatigue strength (see Section 4.3.5.2.2)

[1] If no cut-out wind speed V_{out} is defined, V_{ref} shall be used.

Table 4.3.2 Design load cases for extended design situations

Design situation	DLC	Wind conditions[1]	Other conditions	Type of analysis	Partial safety factors
Power production	9.1	NWP $V_{in} \le V_{hub} \le V_{out}$	Ice formation	F / U	* / N
	9.2	NWP $V_{in} \le V_{hub} \le V_{out}$	Grid failure	F / U	* / N
	9.3	NTM $V_{in} \le V_{hub} \le V_{out}$	Wind farm influence	F / U	* / N
	9.4	NWP $V_{in} \le V_{hub} \le V_{out}$	Temperature effects	F / U	* / N
	9.5	NTM $V_{in} \le V_{hub} \le V_{out}$	Earthquake	U	**
	9.6	NWP $V_{in} \le V_{hub} \le V_{out}$	Earthquake plus grid loss and, if applicable, activation of the safety system by vibration sensor	U	**
Parked (standstill or idling)	9.7	NWP $V_{hub} = 0.8\ V_{ref}$	Earthquake and grid loss	U	**
	9.8	NWP $V_{hub} = 0.8\ V_{ref}$	Temperature effects	U	N

* Partial safety factor for fatigue strength (see Section 4.3.5.2.2)
** Partial safety factor for earthquakes (see Section 4.3.5.4)
[1] If no cut-out wind speed V_{out} is defined, V_{ref} shall be used.

Meaning of the abbreviations in Tables 4.3.1 and 4.3.2:

DLC	Design load case
ECD	Extreme coherent gust with direction change (see Section 4.2.3.2.5)
ECG	Extreme coherent gust (see Section 4.2.3.2.4)
EDC	Extreme direction change (see Section 4.2.3.2.3)
EOG	Extreme operating gust (see Section 4.2.3.2.2)
EWM	Extreme wind speed model (see Section 4.2.3.2.1)
EWS	Extreme wind shear (see Section 4.2.3.2.6)
Subscript	Recurrence period in years
NTM	Normal turbulence model (see Section 4.2.3.1.3)
NWP	Normal wind profile model (see Section 4.2.3.1.2)
F	Fatigue strength
U	Ultimate strength
N	Normal and extreme
A	Abnormal
T	Transport, erection, installation and maintenance

4.3.3.1 Power production (DLC 1.1 to 1.8)

(1) In this design situation, a wind turbine is in operation and connected to the electrical grid.

(2) Deviations from theoretical optimum operating situations, such as yaw misalignment and control system delays, shall be taken into account in the analyses of operational loads.

(3) A possible wind farm influence is not explicitly considered here. If the wind turbine is erected in a wind farm, a site-specific load calculation (see Section 4.3.3.9) shall be performed, or it shall be shown that the conditions prevailing at the site are covered by those used in the load calculations (see Section 4.4).

(4) Design load case DLC 1.1 embodies the requirements for loads resulting from atmospheric turbulence. DLC 1.3 and 1.6 – 1.7 specify transient cases which have been selected as potentially critical events in the life of a wind turbine. In DLC 1.4 and 1.5, transitional events due to grid loss are considered.

(5) DLC 1.1: For this design load case, the discretization of the wind speed intervals (bins) within the wind speed range to be investigated shall not be chosen to be larger than 2 m/s. In the fatigue load calculation, 700 generator switching operations (high speed / low speed and vice versa) per year shall be included, if applicable. Furthermore, 300 changes per year in the mean wind speeds from V_{in} to V_r and back to V_{in} shall be taken into account. 50 changes per year in the mean wind speeds from V_r to V_{out} and back to V_r shall be taken into account.

(6) DLC 1.1, 1.4 – 1.7: Yaw misalignment and the hysteresis shall be considered for yaw movement. If smaller values cannot be verified, an average yaw misalignment of ±8° shall be applied.

(7) DLC 1.3, 1.5 – 1.7: The rotor start positions which lead to the most unfavourable conditions for the wind turbine shall be considered. The intervals between the rotor start positions shall be at most 30° for three-bladed rotors and 45° for two-bladed rotors.

(8) DLC 1.4: The transient switching operations of the wind turbine triggered by grid loss shall be considered with regard to the analysis of fatigue and extreme loads. To account for normal external conditions, 20 grid losses per year shall be assumed as a transient event in simulation. The manufacturer shall specify whether the expected number of occurrence exceeds 20 grid losses per year. Consequently, DLC9.2 shall account for the local grid stability.

(9) DLC 1.5: The grid loss can occur at any time during the course of the gust. The most unfavourable combinations shall be considered. At least the following three combinations of grid loss and gust shall be examined:

- The grid loss occurs at the time of the lowest wind speed.
- The grid loss occurs at the time of the highest gust acceleration.
- The grid loss occurs at the maximum wind speed.

(10) DLC 1.8: This design load case considers humid weather conditions with ice formation. The conditions “ice formation on all rotor blades” and “ice formation on all rotor blades except one” shall be assumed. In the analysis of the fatigue loads, the manufacturer shall define assumptions regarding the duration of operation with ice formation based on the operation and safety system and its manuals. At least 24 h per year with the condition “ice formation on all rotor blades except one” shall be considered according to the Weibull distribution. The ice formation shall be modelled according to Section 4.2.4.2.2. If the turbine is to be installed in areas where a more unfavourable manner of ice formation is to be expected, these load cases shall be considered according to load case DLC9.1.

4.3.3.2 Power production plus occurrence of fault (DLC 2.1 and 2.2)

(1) Any fault in the wind turbine that is significant for wind turbine loading (such as failure of the control or safety system, any internal fault in the electrical system, generator short circuit, malfunction of the pitch or yaw system etc.) shall be assumed to occur during power production.

(2) It may be assumed that independent faults do not occur simultaneously.

(3) DLC 2.1: The occurrence of a fault in the wind turbine which is considered a normal event shall be analysed in DLC 2.1. Exceedance of the limiting values of the control system, e.g. $n \geq n_{4,}$ (Section 2.2.2.6), yaw error, pitch deviation of the blades to each other) shall be investigated. Regarding the consideration of fatigue loading, the manufacturer shall specify the expected frequency of occurrence for the events. As a minimum requirement, at least 10 shutdowns per year due to overspeed n_4 (see Section 2.2.2.6.(4)) and 24 hours per year of operation with extreme yaw error (value equal to the maximum permissible oblique inflow according to Sections 2.3.2.12 and 2.3.2.13) shall be considered. The influence of possible control system malfunctions with direct relevance on the loads shall be considered; see also Section 4.3.4.3.

(4) DLC 2.2: The occurrence of faults in the wind turbine which are considered to be rare events shall be analysed in DLC 2.2. Exceedance of the limiting values for the safety system (e.g. $n \geq n_A$ (Section 2.2.2.6, para 5), $P \geq P_A$ (Section 2.2.2.7, para 3), vibrations, shock (Section 2.3.2.7), runaway of the blade pitch, failure of a braking system (e.g. erroneous activation or non-activation) or runaway of yaw shall be investigated. Furthermore, short circuits in the internal electrical system (see Appendix 4.C) shall be investigated. In the case of non-independent blade pitching, Section 2.2.3.4.2 shall be observed. Regarding the consideration of fatigue loading, the manufacturer shall specify the expected frequency of occurrence for the events.

4.3.3.3 Start-up (DLC 3.1 and 3.2)

(1) This design situation includes all the events resulting in loads on a wind turbine during the transitions from any standstill or idling situation to power production.

(2) DLC 3.1: Per year, at least 1000 start-up procedures at V_{in}, 50 start-up procedures at V_r and 50 start-up procedures at V_{out} shall be considered. If applicable, further start-up procedures shall be taken into account due to site-specific requirements, such as shadow criteria or conditions for installation within a wind farm (curtailment strategy).

4.3.3.4 Normal shut-down (DLC 4.1 and 4.2)

(1) This design situation includes all the events resulting in loads on a wind turbine during normal transitions from power production to a stand-by condition (standstill or idling).

(2) DLC 4.1: Per year, at least 1000 shut-down procedures at V_{in}, 50 shut-down procedures at V_r and 50 shut-down procedures at V_{out} shall be considered. If applicable, further shut-down procedures shall be taken into account due to site-specific requirements, such as shadow criteria or conditions for installation within a wind farm (curtailment strategy).

4.3.3.5 Emergency shut-down (DLC 5.1)

This load case covers manual actuation of the emergency stop pushbutton. For the requirements, see Section 2.3.2.15.

Note:

It is assumed that a reset of the emergency stop function is performed soon after actuation of the emergency stop pushbutton and execution of the emergency stop.

4.3.3.6 Parked (DLC 6.1 to 6.4)

(1) For this design situation, the rotor of a parked wind turbine in stand-by mode is at standstill or idling.

(2) In the design cases DLC 6.1, 6.2 and 6.3, the extreme wind speed model (EWM) shall be applied. In DLC 6.4, the normal turbulence model (NTM) shall be used.

(3) If the wind turbine has a yaw system where the yaw braking capacity will be exceeded during extreme wind situations (e.g. free or semi-free yawing), the turbulent extreme wind speed model shall be applied.

(4) If the wind turbine is subject to large yaw movements, changes in the operating condition or stand-by condition during the increase in the wind speed from normal operation to the extreme condition, this behaviour shall be considered in the calculation.

(5) In the case of a stiff or well-damped wind turbine with low dynamic effect, the steady extreme wind speed model can be applied in the calculation of DLC 6.1 to 6.3. For more flexible wind turbines, which tend towards resonant magnification, the turbulent extreme wind speed model shall be applied in a turbulent simulation or in a quasi-static calculation, with corrections for gusts and the dynamic reaction (see Section 4.3.4.1, para 9).

(6) DLC 6.1: In this load case, transient oblique inflow of up to ±15° for the steady extreme wind speed model, or an average oblique inflow of ±8° for the turbulent extreme wind speed model, shall be assumed if it is ensured that the average yaw misalignment does not lead to larger values and that no slippage of the yaw system can be assured (in this case, an additional yaw error need not be considered). If this cannot be excluded, a yaw error of up to ±180° shall be used.

(7) DLC 6.2: In this load case, a grid failure (see Sections 2.2.2.12 and 2.2.2.13) in an early stage of the storm with the extreme wind situation shall be assumed. A yaw error of up to ±180° shall be assumed if no independent power supply is available that ensures sufficient capacity for at least 7 days of operation for the control system and 6 h of operation for the yaw system.

(8) DLC 6.3: In this load case, the extreme wind with a recurrence period of one year (annual wind) shall be assumed together with an extreme oblique inflow or average extreme oblique inflow. An extreme oblique inflow of up to ±30° for the steady-state extreme wind speed model, and an average oblique inflow of up to ±20° for the turbulent extreme wind speed model, shall be assumed. In this case, an additional yaw error need not be considered.

4.3.3.7 Parked plus fault conditions (DLC 7.1)

(1) This load case considers the non-stand-by state (standstill or idling) resulting from the occurrence of a fault. Deviations from the normal behaviour of a parked wind turbine, resulting from faults in the electrical network or within the wind turbine, shall require analysis. If any fault other than a grid failure produces deviations from the normal behaviour of the wind turbine in parked situations, the possible consequences shall be considered as well. Grid failure (see Sections 2.2.2.12 and 2.2.2.13) in this case shall be regarded as a fault condition and therefore need not be considered together with any other fault of the wind turbine. In case of a braking system failure (erroneous activation or non-activation), the most unfavourable braking torque (min or max) according to Section 4.3.3 (14) shall be considered.

(2) The fault condition shall be combined with the extreme wind speed model (EWM) and a recurrence period of one year. In this load case, transient oblique inflow of up to ±15° for the steady extreme wind speed model, or an average oblique inflow of ±8° for the turbulent extreme wind speed model, shall be assumed. An additional yaw error need not be considered here, unless a failure of the yaw system itself is being investigated. In such a case, a yaw error of up to ±180° shall be used. If slippage of the yaw system cannot be excluded, a yaw error of up to ±180° shall be used.

4.3.3.8 Transport, erection, maintenance and repair (DLC 8.1 to 8.2)

(1) DLC 8.1: The manufacturer shall state all the wind conditions and design situations assumed for transport, erection, maintenance and repair of a wind turbine, and especially up to which maximum average wind speed (10-min mean) and for which oblique inflow the turbine may be erected and maintained. The maximum wind speed specified by the manufacturer (V_T) applies for active work on the wind turbine. If the wind conditions exceed the specified limiting values (with regard to wind speeds and oblique inflow), the work shall be halted.

(2) In the case of conditions for maintenance, particular consideration shall be given to the effect of the various locking devices (e.g. blade pitching, rotor and yaw drive) and the maintenance position which may have been adopted. Even with the rotor locked, the blade pitching system shall be able to move through its entire control range. Verification of standstill without the rotor lock activated shall be provided up to an oblique inflow of ±10° (Section 2.2.3.4).

(3) For the verification of the mechanical brake against slippage (situation after actuation of the emergency stop pushbutton), a transient oblique inflow of up to ±30° shall be assumed for this load case. The rotor positions which lead to the most unfavourable conditions for the wind turbine shall be considered. The intervals between the rotor positions shall be at most 30° for three-bladed rotors and 45° for two-bladed rotors. The most unfavourable braking torque (min or max) according to Section 4.3.3 (14) shall be considered.

(4) DLC 8.2: In this design load case, the situation that the turbine has to be left behind in the locked condition is taken into account. In this load case, transient oblique inflow of up to ±15° for the steady extreme wind speed model, or an average oblique inflow of ±8° for the turbulent extreme wind speed model, shall be assumed if it is ensured that the yaw system is ready for operation during the entire period and that no slippage can be assured (in this case, an additional yaw error need not be considered). If a slippage cannot be excluded, a yaw error of up to ±180° shall be used. The requirements for the locking devices according to Section 2.3.3 shall be met. DLC 8.2 may be omitted if requirements according to Section 2.3.3.2 are met.

Note

It is assumed that the situation with the turbine left in the locked condition has a maximum duration of one day. If it is expected the situation with the turbine in locked condition will last more than 24 hours, or if lengthy grid non-availability is expected, a yaw error of up to ±180° shall be used.

4.3.3.9 Design load cases for extended design situations

(1) DLC 9.1 (Ice formation): This design load case considers ice formation on the wind turbine installed in areas where ice formation is expected in a more unfavourable manner than considered within DLC1.8 (see Section 4.3.3.1 (10)). Based on available site design conditions, the duration of icing and the density of the ice, for example, can be adapted. In case of absence of other information, the ice formation shall be modelled according to Section 4.2.4.2.2.

(2) DLC 9.2 (Grid failure): In this load case, peculiarities arising from connection to an energy consumer (e.g. frequency, voltage and load fluctuations in a weak grid, grid failure and special requirements of the grid operator) shall be taken into account as applicable. Examples of extreme influences on a wind turbine are:

- major frequency, voltage and load fluctuations, also in an isolated grid
- short-circuit in the grid
- special requirements of a grid operator (e.g. fault ride-through capabilities, auto-reclosing cycles)

Details regarding this load case shall be stated by the manufacturer.

(3) DLC 9.3 (Wind farm influence): Influences of a wind farm configuration on the loads due to wind field perturbations in the wake shall be considered. For further detail, see Section 4.4.6.

(4) DLC 9.4 and DLC 9.8 (Temperature effects): Temperature influences according to Section 4.2.4.1 shall be investigated for analyses of the components in accordance with Chapter 6, Chapter 7 and Chapter 8. In the case of extreme temperature influences for site-specific designs, Section 4.4.5.4 and 4.4.5.5 shall be observed.

(5) DLC 9.5 to DLC 9.7 (Earthquakes): The loading caused by earthquakes shall be taken into account in regions at risk from earthquakes.

- DLC 9.5 assumes the occurrence of an earthquake during normal operation.
- DLC 9.6 comprises a superposition of the earthquake and a shut-down procedure possibly triggered by the earthquake. A grid failure as well as the activation of the safety system by vibration sensor triggered by the earthquake shall be considered.
- DLC 9.7 considers a superposition of the earthquake and a previously occurred grid loss.

The loads resulting from earthquakes can be determined in either the frequency or the time domain. In all cases, it shall be ensured that an adequate number of natural modes (≥ 3) are considered and, for calculation in the time domain, an adequate number (≥ 6) of simulations are performed per load case. In general, an elastic load-bearing behaviour shall be assumed for the structure. For certain constructions (e.g. lattice towers), a ductile behaviour may be assumed. The damping to be applied shall then be determined appropriately for the construction in consultation with GL. If ductile behaviour is assumed, it shall be necessary to inspect the structure after earthquakes have occurred. The scope of such inspections shall be agreed with GL and documented in the manuals. Further information on the influence of earthquakes reference is given in Section 4.4.5.2.

4.3.4 Load calculations

Loads as described in Sections 4.3.2.1 to 4.3.2.4 shall be taken into account for each design load case. Where relevant, the following influences shall also be taken into account:

4.3.4.1 General influences

- wind field perturbations due to the wind turbine itself (wake-induced velocities, tower shadow, tower upwind effect etc.)
- the influence of three-dimensional flow on the blade aerodynamic characteristics (e.g. three-dimensional stall and aerodynamic tip loss)
- dynamic stall effects of the airflow for the profiles used
- unsteady aerodynamic effects
- aeroelastic effects
- aerodynamic asymmetries, which can arise through production or assembly tolerances of the rotor blades. A verified tolerance shall be observed. If this is not (or not yet) known, a deviation of the blade angle of attack of ±0.3° (i.e. for a three-bladed rotor: blade 1 at 0°, blade 2 at –0.3°, blade 3 at +0.3°) shall be assumed.
- structural dynamics and the coupling of vibrational modes: The elasticity of the blades, elasticity of the drive train and generator (drive train dynamics) as well as the tower bending shall be considered. The elastic mounting of the machinery, vibration dampers, the torsional stiffness of the tower and the influence of the foundation shall also be included, if their influence cannot be neglected.
- eccentricity: For at least the blades, the hub and all relevant components of the drive train, the actual mass eccentricity according to the manufacturer's specifications shall be taken into account.
- dynamic response when parked (standstill or idling) and application of the EWM (see Sections 4.3.3.6 to 4.3.3.8) with steady wind model by a gust reaction factor to the tower loads (see Section 6.6.5.3)
- Additionally, in the case of horizontal-axis turbines with active yaw control, operation of the yaw system during the entire service life shall be considered if the yaw speed exceeds 15/R in °/s or the yaw acceleration exceeds $450/R^2$ in $°/s^2$ (where R is the rotor radius in m).

4.3.4.2 Operational influences

(1) Static and load-dependent bearing friction moments (especially blade pitch bearing, yaw bearing) shall be considered.

(2) The behaviour of the control and safety systems of the wind turbine shall be taken into account in the load case definitions and during all load simulations performed.

(3) In case the control system provides active features for load reduction, it has to be ensured that they are in operation over the whole lifetime of the wind turbine. Possible malfunctions of these features shall be detected and consequences considered, see Section 2.1.3. The influence of the malfunctions of the control system features, including corrective actions, shall be considered in load analysis as load case DLC 2.1; see Section 4.3.3.2, para 3. In case any errors are detected with delay, this delay shall also be considered in the extreme and fatigue load analysis.

4.3.4.3 Operation within the resonance range of the tower

If the operation of the wind turbine is approved within the resonance range of the tower with a tolerance of ±5 % of the tower's natural frequency (Section 6.6.5.1), suitable vibration monitoring systems shall be provided (Section 2.3.2.8). With the evaluation (Section 4.B.3) of the load calculation, suitable threshold values for permissible vibrations shall be defined and taken into account.

4.3.5 Partial safety factors for loads

4.3.5.1 Partial safety factors for the loads in the analysis of the serviceability limit state (SLS)

(1) For the analysis of the serviceability limit state, see Section 1.3.2.2.2, a partial safety factor for loads of $\gamma_F = 1.0$ shall be used for all load components.

(2) It shall be verified that no deflections endangering the safety of the wind turbine occur under the design conditions listed in Table 4.3.1 and, if applicable, Table 4.3.2. One of the most important considerations is that no contact can be permitted to occur between the blades and the tower. The maximum elastic deflection in the most unfavourable direction shall be determined for the load cases listed in Table 4.3.1 and, if applicable, Table 4.3.2.

(3) In consultation with GL, methods of statistical extreme value analysis (e.g. [4.9] to [4.13]) may also be used for the blade deflection. An extrapolation time of 50 years shall be applied.

(4) Observance of the permissible clearance between blade and tower shall be verified in accordance with Section 6.2.4.1, para 7.

4.3.5.2 Partial safety factors for the loads in the analysis of the ultimate limit state (ULS)

4.3.5.2.1 Partial safety factors for ultimate loads in the analysis of the ultimate strength

(1) Ultimate loads shall be used for the analysis of the ultimate strength, loss of stability and loss of equilibrium; see Section 4.3.3, para 11. If the loads of different causes can be determined independently of each other, the partial safety factors for the loads shall have the minimum values given in Table 4.3.3.

(2) In many cases, especially when unsteady loads lead to dynamic effects, the load components cannot be determined independently of each other. In these cases, the highest partial safety factor of the corresponding design situation in Table 4.3.3 shall be applied for the partial safety factors for the loads γ_F (see also Section 1.3.3).

4.3.5.2.2 Partial safety factor for the loads in the analysis of the fatigue strength

The partial safety factor for the loads shall amount to $\gamma_F = 1.0$ for all design situations.

4.3.5.3 Special partial safety factors

Smaller partial safety factors for loads may be used after consultation with GL, if the loads were determined from measurements, or from analyses verified by measurements, with a higher level of confidence than is normally the case. The values of all partial safety factors shall be given in the design documentation.

4.3.5.4 Partial safety factor for the loads during earthquakes

The safety factor for the loads during earthquakes is $\gamma_F = 1.0$.

Table 4.3.3 Partial safety factors for loads γ_F

Source of loading	**Unfavourable loads**			**Favourable loads**
	Type of design situation (see Tables 4.3.1 and 4.3.2)			**All design situations**
	N **Normal and extreme**	**A** **Abnormal**	**T** **Transport and erection**	
Aerodynamic	1.35	1.1	1.5	0.9
Operational	1.35	1.1	1.5	0.9
Gravity	1.1/1.35*	1.1	1.25	0.9
Other inertial forces	1.25	1.1	1.3	0.9
Heat influence	1.35	–	–	–
* in the event of the masses not being determined by weighing.				

4.4 Site Design Conditions

4.4.1 General

(1) The site design conditions shall denote all external influences acting on the wind turbine from outside. These are influences resulting from orographical, topographical and meteorological conditions as well as from other external sources.

(2) Within the scope of the site design conditions, the conditions prevailing at the installation site shall be analysed. This includes the conditions listed in the following sections. Other conditions influencing the structural integrity of the wind turbine not listed in these sections should also be stated. Locations at which special events, e.g. cyclones and floods, may be expected shall be considered in consultation with GL.

(3) Furthermore, in the case of confirmation of an existing certificate, a comparison shall be undertaken with the conditions assumed during the certification.

(4) The site design conditions shall be taken as basis for analysing the structural integrity of a wind turbine design (e.g. calculation of site-specific loads).

4.4.2 Determination of the wind conditions

(1) The basic parameters listed below for the wind at the turbine site shall be determined:

- air density ρ
- reference wind speed V_{ref}
- annual average wind speed V_{ave}
- wind speed distribution
- wind direction distribution (wind rose)
- turbulence intensity I_{15} for $V_{hub} = 15$ m/s
- wind shear (see also Section 4.2.3.1.2)
- inclination of the average wind direction from the horizontal plane

(2) The wind conditions can be determined at the intended site by measurements. The site conditions shall be correlated with long-term records of the local meteorological stations. The measurements shall be performed in accordance with:

- IEC 61400-12.1 [4.20]
- MEASNET Procedure [4.21]

in their latest versions.

(3) The measurement period shall be sufficiently long to obtain reliable data for at least 6 months. If seasonal variations contribute significantly to the wind conditions, the measurement period shall take account of this influence.

(4) For the determination of V_{ref} from averaging of long term data, measurements of at least 7 to 10 years (depending on averaging procedure) have to be evaluated. For the determination of V_{ave} from averaging of long term data, measurements of at least 10 years have to be evaluated. The averaging procedure shall be agreed with GL.

(5) I_{15} is the characteristic value of the turbulence intensity at hub height for a 10-min mean of the wind speed amounting to 15 m/s. The characteristic value is determined through addition of the measured standard deviation of turbulence intensity to the measured mean value of the turbulence intensity.

(6) The value I_{15} should be determined from the measured data at wind speeds greater than 10 m/s, by means of suitable statistical methods. If topographical or other local conditions are able to influence the turbulence intensity, these effects shall be included in the data.

Note:

If e.g. trends with a low frequency occur in turbulence data, the turbulence intensity and other parameters should be analysed with care.

(7) Alternatively, the relevant characteristic values of the wind may be determined by numerical methods in consultation with GL. Standard linkages of external parameters, such as effective fetch of the wind, roughness length, mean wind speed etc., to power spectra and coherence functions of the wind speed are regarded as fundamentally permissible as the starting point for a description of the turbulence.

(8) The interval of each wind bin may be at most 2 m/s, and that of the wind direction sector at most 30°. All parameters, except the air density, shall be submitted as a function of the wind direction averaged over 10 minutes.

(9) The properties of the anemometer, the sampling rate and the averaging period for the logging of the measurement values can influence the determination of the turbulence intensity. These influences shall be taken into account in forecasting the turbulence intensity from measurements.

(10) In complex terrain (see Section 4.4.7), the influence of the topography on the wind speed, the wind profile, the turbulence intensity and any inclination of flow shall be considered at each turbine site. It shall be observed that the increase in wind speed at hilltops can influence the reference wind speed V_{ref} as well as the mean wind speed V_{ave} .

(11) The mutual influence of wind turbines in a wind farm shall be taken into account, e.g. wake effects (see Section 4.4.6), and reduction of wind velocity.

4.4.3 Determination of the electrical power network conditions

The electrical conditions shall be determined at the grid connection point between the wind turbine and the existing electrical grid at the intended site, in order to ensure compatibility between the turbine and, where necessary, all electrical equipment located between the turbine and the grid (see also Section 4.2.5). This shall include the following items at least:

- normal supply voltage and fluctuations
- normal supply frequency and fluctuations
- voltage symmetry
- symmetrical and asymmetrical faults
- number and type of the electrical grid outages and their average duration
- Special features of the electrical grid at the site as well as requirements of the local grid operator shall be taken into account. These may be:
    - auto-reclosing cycles
    - short-circuit impedance at the connection points of the wind turbine
    - harmonic voltage distortion from the turbine's power system

4.4.4 Determination of the foundation / soil properties

The foundation (soil properties) at the intended site shall be assessed in accordance with the local situation (subsoil, building codes) by a geotechnical report as a rule. For this, Section 6.7.6 shall be taken into account.

4.4.5 Determination of other environmental conditions

4.4.5.1 General

(1) The environmental conditions mentioned in Section 4.2.4 shall be determined for the comparison with the assumptions made for the design of the wind turbine.

(2) For the determination of normal and extreme temperature ranges from averaging of long term data (e.g. for cold climate application), measurements of at least 7 years shall be evaluated. The averaging procedure shall be agreed with GL.

4.4.5.2 Influence of earthquakes

4.4.5.2.1 General

The loading caused by earthquakes shall be taken into account in regions at risk from earthquakes. In the absence of any locally applicable regulations, a procedure based on Eurocode 8 [4.14] and/or API [4.15] may be followed in consultation with GL.

4.4.5.2.2 Acceleration

The investigation of the earthquake-generated loads is based on the combination of the wind loads and an earthquake acceleration with a recurrence period of 475 years.

4.4.5.3 Corrosion, erosion

It shall be checked whether the intended corrosion protection is adequate for the site. Protection against corrosion and erosion shall therefore be taken into account by the selection of suitable materials and appropriate coatings and protective coverings, plus regular inspection.

4.4.5.4 Extreme temperatures – cold climate

For the certification of wind turbines for extreme temperatures – cold climate, reference is made to the GL Wind Technical Note 067 "Certification of Wind Turbines for Extreme Temperatures (here: cold climate)" [4.16].

4.4.5.5 Extreme temperatures – hot climate

The certification of wind turbines to be erected at sites with a temperature higher than +50 C shall be performed in consultation with GL.

4.4.6 Wind farm influence

(1) If wind turbines are erected in wind farms, the influence exerted on the loads by wind field perturbations in the wake shall be considered. This shall be considered for both a simple shadow effect and for superimposed wake interaction. For large wind farms, an increase in the environmental turbulence or terrain roughness shall be taken into account.

(2) The mutual influence of wind turbines through the wake interaction behind the rotor shall be considered in a wind farm configuration up to a distance of 10 D.

(3) Calculation models (e.g. S. Frandsen [4.17] or “Dynamic Loads in Wind Farms II” (DLWF II) [4.18]) may be used in consultation with GL. The models shall be validated.

(4) For the erection of the turbines within a wind farm, the influence on the extreme and fatigue loads shall be determined.

4.4.7 Complex terrain

4.4.7.1 General

Special forms of terrain, particularly elevations, may produce velocity and turbulence distributions over the height which differ from those mentioned in Section 4.2 and are to be taken into consideration accordingly.

4.4.7.2 Definition

(1) The complexity of the terrain can be determined through the deviation of the topography from a plane. A location that does not meet the conditions listed in Table 4.4.1 shall be regarded as complex terrain.

Table 4.4.1 Criteria for the definition of complex terrain

Distance (x) from the turbine	Inclination (Φ) of the plane	Deviation of the terrain from the plane (Δh)
< 5 h	< 10°	< 0.3 h
< 10 h		< 0.6 h
< 20 h		< 1.2 h
where h is the hub height.		

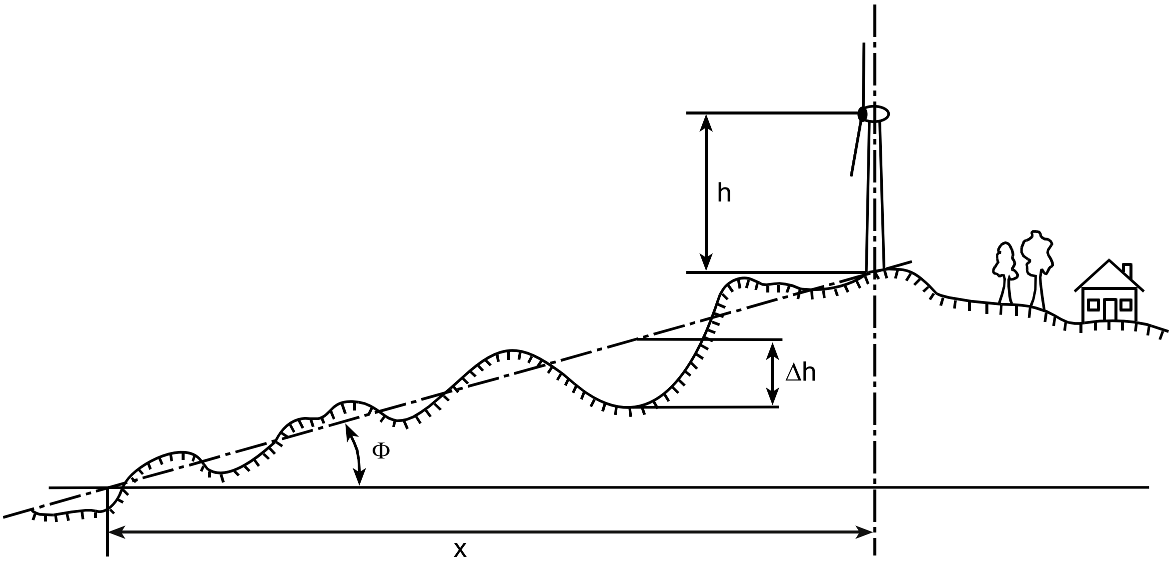


Fig. 4.4.1 Criteria for complex terrain

(2) The inclination of the plane shall be set so that it represents the best possible approximation of the terrain from the wind turbine (basepoint) to the viewpoint. The deviation of the terrain from the plane shall be determined in the vertical direction; see also Fig. 4.4.1.

4.4.7.3 Wind conditions

In complex terrain, the turbulence intensity shall be determined with special care. If measurements or calculations of greater accuracy are not available, then in consultation with GL the longitudinal, lateral and vertical component of the turbulence intensity shall be increased. The inclination of the airflow at the plant shall be assumed equal to the maximum inclination of the plane defined in Section 4.4.7.2. In addition, the extreme wind shear at the site shall be determined. The determination of the extreme wind shear can be performed by using a statistical extrapolation method (e.g. [4.6] to [4.13]). Other extrapolation methods can be applied in consultation with GL.

4.4.8 Comparison through wind data

The validity of the certification can be confirmed through a comparison of the wind data, if the values obtained at the site with regard to the following conditions are more favourable than for determination of the load assumptions according to Section 4.2 and 4.3:

- The 50-year recurrence wind speed is less than V_{ref}. (Alternatively, the comparison can be made through the gust wind speed or the stagnation pressure.)
- The mean over many years of the wind speed is less than V_{ave}.
- Between the wind speeds $0.2 \cdot V_{ref}$ and $0.4 \cdot V_{ref}$, the probability density function of the wind speed at hub height shall be smaller than that assumed for the certification.
- Between the wind speeds $0.2 \cdot V_{ref}$ and $0.4 \cdot V_{ref}$, the turbulence intensity occurring at the site (see Section 4.4.2) shall be lower than that assumed for the certification. The probability of occurrence for the turbulence intensity at the site shall be considered in the comparison. Under consideration of turbulence magnification owing to wake effects, it shall be shown that, between the wind speeds $0.8 \cdot V_r$ and V_{out}, the turbulence intensity occurring at every turbine in the wind farm is lower than that assumed for the certification.
- In complex terrain, it shall be shown for all three components of the turbulence intensity that they are lower than that assumed for the certification.
- The maximum upflow occurring for all wind directions shall be lower than the upflow assumed for the certification.
- The power law exponent and the extreme wind shear shall be lower for all wind directions than those assumed for the certification.
- The average air density at the site should be lower than that assumed for the certification. If this is not the case at the site, other comparative studies can be performed.

4.5 Load-Relevant Control and Safety System Functions

4.5.1 General

(1) Due to its influence on the mechanical loads the performance of the control and safety system (see section 2.2) is essential for the safety of personnel as well as the structural integrity of the wind turbine. Section 4.5 addresses the functions of the control and safety system which are load-relevant for the wind turbine. These Load-Relevant control and safety system Functions (LRF) comprise in detail:

1) functions of the control system to operate the wind turbine in the state of:
   - power production
   - start-up
   - shut-down
   - parked
2) protection functions (see Section 2.2.2.3)

(2) The LRF are implemented in the load simulation model and in the wind turbine. Thorough development and verification of the LRF is essential both for the calculation of the load assumptions and the application in the wind turbine. This includes their intensive testing, starting at early stages of the development.

(3) An early contact between the manufacturer and GL is advisable, with a view to achieving timely agreement on the scope of the assessment.

4.5.2 Scope

(1) For the approval of the load assumptions, the LRF shall be verified. The scope for its verification shall cover all functions which can influence the loads of the wind turbine in normal operation or in any malfunction. This comprises the control software executing the LRF for the calculation of the load assumptions. It comprises also the hardware, firmware and the application software executing the LRF at the wind turbine. Special emphasis shall be laid on actuator response and delays in the system.

(2) The verification of the LRF shall address the aspects of safety, functionality, performance and robustness. Attention shall be given to the interfaces between different subsystems, including the consequences of asynchronous operation where appropriate.

(3) The verification shall ensure an appropriate linkage between the design of the LRF executed during the calculation of the load assumptions and its implementation at the wind turbine.

(4) To verify the LRF for the calculation of the load assumptions and suitable performance of the wind turbine, one of two different approaches can be chosen for the certification as alternatives, see Sections 4.5.3 and 4.5.4. Sections 4.5.5 and 4.5.6 shall be applied for both alternatives.

4.5.3 LRF verification by controller model description (Alternative 1)

4.5.3.1 General

The intent is to verify the LRF within a parallel process. For that, documentation of the LRF shall be submitted which makes it possible to build up a model of the controller and the creation of executable software for the parallel calculation within the certification of the load assumptions. The intention is to reveal documentation defects and errors in controller implementation (e.g. parameters and unit transformations). In combination with testing, the assessment is intended to lead to an improved reliability of the control software used within the calculation of the load assumptions.

4.5.3.2 Assessment documentation

(1) For the simulation of the plant behaviour and the associated loads, a description shall be submitted for all relevant control circuits and monitoring devices that have an influence on the load response of the wind turbine (e.g. power, rotational speed, yaw movement).

(2) The behaviour of the control of the wind turbine shall be described by a block diagram, if applicable with hierarchical subdivisions. For each block, formulae shall be given to describe unambiguously the input/output response and initial state.

(3) The block circuit diagram shall include the input and output signals of the controller and the interconnections of the blocks used. Signal paths shall be provided with arrows to indicate their direction of effect. Each signal in the block circuit diagram shall be named unambiguously.

(4) The functional relationship between inputs and outputs of the individual blocks of the controller shall be described in the form of discrete-time static or dynamic model equations (for linear blocks, Z-transfer functions are permissible) with statement of the time step, or in another reasonable way.

(5) The interface between the control algorithms and the rest of the turbine control system shall be presented, i.e. inputs and outputs need to be qualified and linked explicitly with turbine model signals.

(6) The turbine model for load simulation shall include suitable models for required measurement signals, actuator dynamics, time delays and noise levels. The respective models and parameters shall be documented to allow a comparison after the determination of the real behaviour during prototype testing; see Section 10.6.

(7) The manufacturer shall demonstrate the behaviour of the controller with test cases of time series in closed-loop simulation. Furthermore, test cases with the controller operating in isolation shall be submitted, e.g. controller input signal perturbation tests. The test cases to be submitted shall be agreed with GL.

(8) The signals and parameters needed for the function of the controller shall be given with their units in summarized form in a table. To ease further parameterization of the controller, it is suggested that all parameters are summarized within an accessible, external file.

4.5.4 LRF verification by functional testing (Alternative 2)

4.5.4.1 General

The manufacturer shall establish quality management procedures on the development process of the controller comprising at least the LRF of the wind turbine, especially for the calculation of the load assumptions. The manufacturer shall develop and improve the LRF according to the process defined. Testing of the LRF software and hardware during the development is required. The load assessment at GL will be performed with the same control software as used by the manufacturer.

4.5.4.2 Description of controller development process

(1) A controller development process shall be set up for all relevant parts of the LRF development clearly describing the concept of verification for single components of the LRF and the complete system. The controller development process description shall require appropriate methods and specifications for testing of the software and hardware including performance requirements for testing results. The development process description shall include test results and their evaluations in a reviewable format for assessment. Modifications to the LRF due to unmet performance requirements shall be documented as well.

(2) For better maintainability, legibility and failure prevention, the software should be developed according to a software style guide. The software style guide should be submitted to GL.

(3) The description of the controller development process is complemented by the requirements set out in Sections 4.5.5 “Transfer of controller from simulation stage to onsite wind turbine” and 4.5.6 “System version control”.

4.5.4.3 Testing

(1) The testing shall comprise the operation of the LRF over all load-relevant scenarios, as also required for load calculation according to Section 4.3. The testing shall support the aim of comparable performance of the LRF in load simulation and on the wind turbine. An appropriate testing coverage for the software and hardware shall be achieved. For that, the manufacturer shall choose various testing environments, depending on the purpose of the test. The choice of testing environment and test cases may also be influenced by technical constraints of the manufacturer’s development process and the special wind turbine design. A high coverage of the system by real hardware components instead of emulation shall be striven for. A test report comprising the presentation and analysis of results and conclusions including a comparison of the results from the testing and load simulations shall be submitted to GL.

(2) Software testing during the development shall be performed e.g. by code inspection, walk through, white box, black box and software-in-the-loop tests, possibly applying the software also used for load simulation.

(3) Testing including controller hardware components shall be performed in a hardware-in-the-loop environment e.g. by using:

a) complete, cross-compiled control system software applied on the PLC in connection with a wind turbine simulation software

b) a test environment applying single machinery components (e.g. actuators, sensors)

c) an assembled wind turbine nacelle on a test stand with emulation of external conditions

d) a prototype wind turbine

Emulation of hardware shall be agreed with GL.

(4) An inspection of selected tests shall be performed by GL. The scope shall be agreed with GL and can be performed in the manufacturer's controller laboratory, on a prototype wind turbine or in parts also at a sub-supplier's laboratory. This comprises the inspection of the software and hardware and the inspection of operational tests of normal operation and malfunctioning scenarios. It shall be possible on request to retrace the steps of development.

(5) In case the required extent of hardware testing cannot be fulfilled completely during the A-Design Assessment because hardware is not available, the A-Design Assessment can be completed without these tests. Then, the outstanding tests will be delayed until the measurement of loads during the prototype testing as per Section10.5.5, and the assessment completed in this context.

(6) Examples for software and hardware test cases include:

General:

– system identification of first prototype wind turbine
– tests which demonstrate the performance during steady operation cases and transient events
– tests which demonstrate the performance of fatigue and extreme load behaviour
– tests on the functionality of interfaces between different subsystems, including the consequences of asynchronous operation where appropriate
– tests of health monitoring (especially of the pitch system)
– tests on error check procedures and internal control system consistency checks (i.e. the plausibility of input signals)
– tests on the robustness of the system (numerical robustness, influence of unmodelled dynamics and external conditions)
– tests which demonstrate performance of subsystems
– tests of alarm system
– tests on interaction of LRF with safety system
– step impulse tests
– sine sweep tests

Delays and dynamics:

– actuator response tests (delay and dynamics)
– tests revealing and considering critical delays (e.g. in watchdog and safety system)
– tests on sensor dynamics

Failure:

– tests on internal control system failures
– tests on sensor and actuator failure
– tests on communication failures within the control system

Noise:

– controller input signal perturbation tests
– tests superimposing pitch disturbance and generator torque disturbance
– tests on noise contamination of sensor signals

The failure cases may be derived from an investigation of worst-case scenarios or FMEA.

4.5.4.4 Assessment documentation

(1) For the purpose of load calculation during the assessment of the loads at GL, control software executing the LRF shall be submitted applied together with the load calculation software. This can either be a cross-compiled version of the software as an executable file (e.g. DLL, *.EXE), or the software can be provided on the wind turbine controller hardware with suitable interfaces to the load calculation software. The executable file shall have an interface to be connected to load calculation software. The design of the interface shall be agreed with GL, enabling GL to successfully connect the executable file to the load calculation software. The executable file shall give GL access to all LRF functions as also used within the calculation of the load assumptions of the manufacturer. The executable file shall furthermore provide access to all relevant parameters of the controller within an external file. The documentation shall include an operating manual and the description of the functional characteristics.

(2) With respect to Sections 4.5.4.2 and 4.5.4.3, the following documentation associated with the LRF shall be submitted as well:

Specification:

– list of functionalities of the system
– product specifications including human machine interface (HMI)
– overview descriptions of functions, together with drawings showing the functional relationships, interfaces between systems and the spatial arrangement of the hardware at the wind turbine

QM documentation:

- software quality assurance plan
- system version control
- software style guide, see Section 4.5.4.2, para 2

Test plan for software and hardware tests:

- test specification
- test schedule and responsibilities
- description of test environment setup

(3) If other proofs and tests provided by the manufacturer are of an equivalent nature, they may be recognized.

4.5.5 Transfer of controller from simulation stage to onsite wind turbine

The development process shall comprise documentation which shows how the LRF, as used within the load calculation, will be transferred to the hardware and its application software at the wind turbine. It shall be ensured that the functions and performance are correctly transferred to the wind turbine. If applicable, this includes intermediate stages, e.g. testing within a hardware-in-the-loop environment, manual programming of the routines with subsequent testing or automatic compilation processes.

4.5.6 System version control

(1) With respect to the LRF, a quality management process shall be set up to clearly define and document the version numbers of the constituent elements of the control system (e.g. controller software version, parameter definition version, subsystem firmware version). The documentation to be submitted shall comprise the following:

(2) A system version control shall be implemented to document subsequent modifications of the system in a retraceable manner. The numbering of the system version control shall differentiate between grades of relevance. Modifications of LRF are subject to re-certification of the respective parts of the whole process and, if relevant, also the load assumptions and component verification. Other load-relevant modifications shall be classified such that they are covered by the certification. The grading of the system version control shall be agreed with GL.

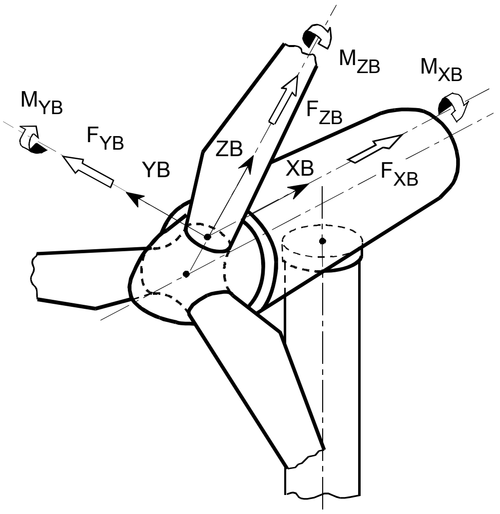
(3) The system version control shall comprise a configuration management which allocates a permissible configuration of wind turbine, e.g. tower, rotor blades etc., to the LRF implemented in the application software in the wind turbine. The user interface at the wind turbine shall give access to the actual system version installed. This information may be reviewed during Testing of Wind Turbines (see Chapter 10) and during Periodic Monitoring (see Chapter 11).

Appendix 4.A Coordinate Systems

In general, the coordinate systems can be chosen freely. By way of suggestion, possible coordinate systems, together with their origin and orientation, are shown in the following diagrams. As a simplification, representation of the rotor axis tilt angle and cone angle was omitted.

4.A.1 Blade coordinate system

The blade coordinate system has its origin at the blade root and rotates with the rotor. Its orientation to the rotor hub is fixed.

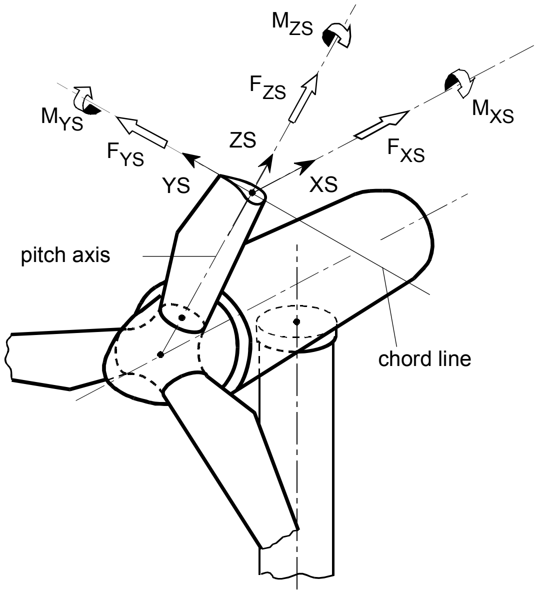


XB	in direction of the rotor axis
ZB	radially
YB	so that XB, YB, ZB rotate clockwise

Fig. 4.A.1 Blade coordinate system

4.A.2 Chord coordinate system

The chord coordinate system has its origin at the intersection of the corresponding chord line and the blade pitch axis. It rotates with the rotor and the local pitch angle adjustment.

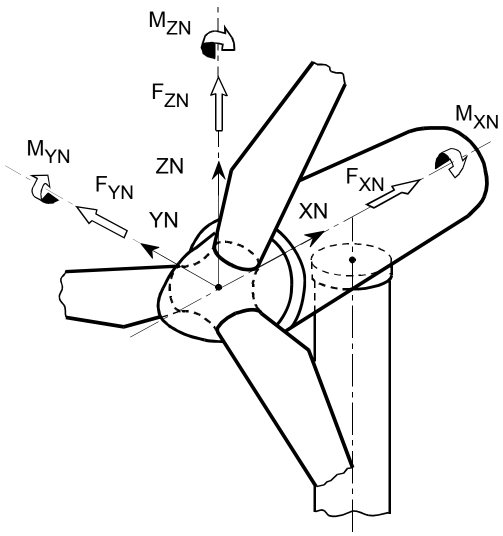


YS	in direction of the chord, orientated to blade trailing edge
ZS	in direction of the blade pitch axis
XS	perpendicular to the chord, so that XS, YS, ZS rotate clockwise

Fig. 4.A.2 Chord coordinate system

4.A.3 Hub coordinate system

The hub coordinate system has its origin at the rotor centre (or any other position on the rotor axis, e.g. hub flange or main bearing) and does not rotate with the rotor.

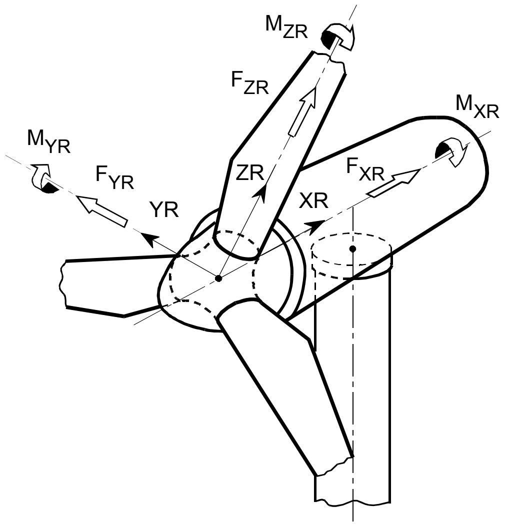


XN	in direction of the rotor axis
ZN	upwards perpendicular to XN
YN	horizontally sideways, so that XN, YN, ZN rotate clockwise

Fig. 4.A.3 Hub coordinate system

4.A.4 Rotor coordinate system

The rotor coordinate system has its origin at the rotor centre (or any other position on the rotor axis, e.g. hub flange or main bearing) and rotates with the rotor.

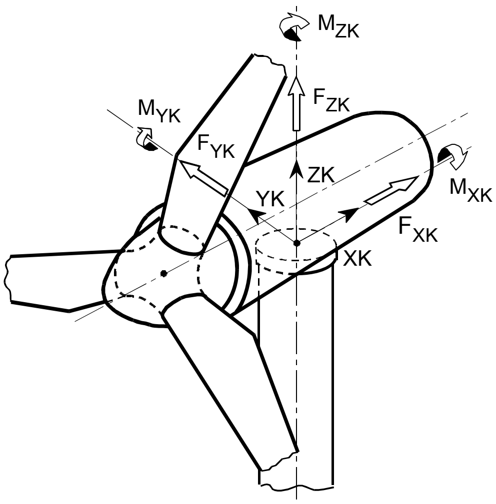


XR	in direction of the rotor axis
ZR	radially, orientated to rotor blade 1 and perpendicular to XR
YR	perpendicular to XR, so that XR, YR, ZR rotate clockwise

Fig. 4.A.4 Rotor coordinate system

4.A.5 Yaw bearing coordinate system

The yaw bearing coordinate system has its origin at the intersection of the tower axis and the upper edge of the tower top and rotates with the nacelle.

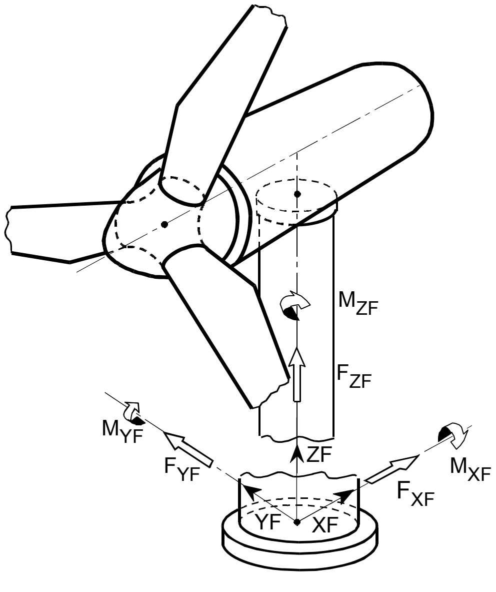


XK	horizontal in direction of the rotor axis, fixed to nacelle
ZK	vertically upwards
YK	horizontally sideways, so that XK, YK, ZK rotate clockwise

Fig. 4.A.5 Yaw bearing coordinate system

4.A.6 Tower coordinate system

The tower coordinate system has its origin at the intersection of the tower axis and the upper edge of the foundation, and does not rotate with the nacelle. In addition, other locations on the tower axis are also possible.



XF	horizontal
ZF	vertically upwards in direction of the tower axis
YF	horizontally sideways, so that XF, YF, ZF rotate clockwise

Fig. 4.A.6 Tower coordinate system

Appendix 4.B Evaluation of the Loads

4.B.1 Presentation of load case definitions

(1) All calculated load cases shall be listed. For each load case, the principal simulation parameters (wind shear, wind model, possible ice loads, upflow, simulation duration etc.) as well as a description of the control and safety system parameters that are necessary for the load cases in question (braking procedures, shut-down procedures, yawing manoeuvres, delay times etc.) shall be specified.

(2) The variations of the load case in relation to the principal data of the load case definition shall be listed together with the filename of the time series with the associated parameters (e.g. wind speed, gust characteristics, oblique inflow, criteria for the activation of control or safety actions etc.).

(3) If a turbulent wind model is used for the load cases with wind conditions from the EWM model (see Section 4.2.3.2.1), a choice can be made between two methods of evaluating the extreme loads.

(4) For the first method, the selection of three representative time series used out of the total number of at least 15 time series with different turbulent seeds shall be presented. This can be done e.g. through suitable averaging procedures.

(5) From the three simulations, the maximum loads shall be evaluated, whereby for each load component the highest loading from the three simulations shall be taken into account. The evaluation shall be performed for all steps to be investigated and shall be considered in the selection of the design loads for rotor blade, machinery and tower. All (at least 15) simulated time series and the selection procedure shall be submitted.

Notes:

The longitudinal turbulence intensity can be calculated beforehand using a numerical method (e.g. ESDU E 0108 [4.19]).

(6) As an alternative to the first method, the NTM turbulence model (see Section 4.2.3.1.3) can be used as described for the EWM model. The evaluation of extreme loads shall be performed by using a statistical extrapolation method (e.g. [4.9] to [4.13]). Other extrapolation methods can be applied in consultation with GL.

4.B.2 Presentation of the results

4.B.2.1 General

(1) In general, a distinction is made between extreme loads and fatigue loads when presenting the results. As a matter of principle, all loads used for the analyses of the component dimensioning shall be specified. The loads shall be presented in the same way as applied in the design process. In addition, the load evaluations shall be specified as described in Sections 4.B.2 and 4.B.3.

(2) All time series of the calculated extreme and fatigue load cases and an appropriate viewer program shall be supplied on computer storage media (e.g. hard drive, DVD, CD-ROM) in universal readable format (e.g. ASCII, XLS) or including appropriate conversion tools.

4.B.2.2 Extreme loads

(1) The results of the extreme load evaluations, including the partial safety factors, shall be presented in tabular form for the positions investigated (e.g. blade sections, blade root, rotor shaft, yaw system, tower etc.). This shall contain a brief description of the load case with statement of the partial safety factors applied. The following presentation format is recommended: The extreme values (maxima and minima) of the corresponding load component are located on the diagonal. The simultaneous loads of the other load components are given in the rows (see Table 4.B.1).

(2) For the extreme loads in the chord coordinate system, a table of the loads including the partial safety factors and a table of the loads excluding them shall be given for each blade section to be examined.

(3) For the extreme loads in the tower coordinate system, a column shall be added to the table for the wind speed and wind direction belonging to the extreme load situation (the sign of the wind direction shall be indicated in a sketch or stated in accordance with the coordinate systems listed in Appendix 4.A). A table of the loads including the partial safety factors and a table of the loads excluding them shall be given in each case.

(4) The quasi-permanent combination of actions for reinforced concrete foundation structures shall be the actions of DLC 1.1 and DLC 6.4, being evaluated with a probability of $p_f = 10^{-2}$ (equivalent to 1750 h in 20 years).

Note:

Alternatively, the actions of DLC 1.1 and 6.4 which occur more than 10^4 times are recommended as a conservative approach.

(5) The extreme loads of the pitch drive actuator torque (min/max) shall be given for all load cases without pitch activity (braked pitch) and separately for all load cases with pitch activity. The simulation of the pitch drive actuator torque shall include effects from the aerodynamic pitch torque, the blade bearing and pitch gearbox friction and the pitching inertia of rotor blade and pitch drive.

(6) With regard to the maximum loads in the blade coordinate system, a table shall be compiled with all the corresponding loads from all the blade connections.

(7) With regard to the maximum bending moment in the hub coordinate system, a table shall be compiled with all the corresponding loads from all the blade connections.

Note:

Following the evaluation of the extreme loads with or without partial safety factors, differing load cases may become relevant.

4.B.2.3 Fatigue loads

(1) In addition to the time series required in Section 4.B.2.1, all results of the evaluation shall be submitted in formats which can be edited by computer.

(2) For the evaluation of the fatigue loads, it is generally required that all design load cases of the fatigue strength shall be included (DLC 1.1, DLC 1.4, DLC 1.8, DLC 2.1, DLC 2.2, DLC 3.1, DLC 4.1, DLC 6.4 and DLC 9.1 to DLC 9.4, if applicable).

(3) The assumptions made in the calculation of the fatigue loads shall be specified. These include e.g. the mean annual wind speed, the parameters of the wind speed distribution, the operating life etc.

(4) For all load components, accumulated fatigue spectra within the simulated operating life shall be given in tabular, and if necessary graphic, form. In addition, equivalent constant-range spectra shall be computed from the accumulated fatigue spectra and also specified. Here the reference load cycle number n_{ref} shall be stated. Equivalent fatigue loads can be presented in tabular form for all material-relevant slope parameters of the S/N curves, in accordance with Table 4.B.2.

(5) For dynamically loaded components of fibre reinforced plastic (GRP/CRP), such as the rotor blade, the Markov matrices (range-mean matrix) shall be given in addition at the sections investigated.

(6) In particular, for the evaluation of the fatigue loads at the blade root, the following procedure shall be observed:

(7) Apart from the evaluation for the bending moments in the flapwise and edgewise directions (Mx and My), the angular sector between these bending moments and the subsequent sector up to 90° shall be examined, so that a total sector of 180° is obtained. These bending moments shall be computed at angular intervals of at least 15°.

(8) Without further evaluation, this examination can be dispensed with if the fatigue loads for the flapwise and edgewise directions are multiplied by a factor of 1.2.

(9) For the components of the blade pitching system, the drive train (main bearing, gear box, coupling etc.) and the yaw system, the average values from the fatigue loads as well as the distribution of the load duration distribution (LDD) shall be specified for the relevant load components (see also Chapter 7). For the blade pitching system, the LDD shall be specified for the pitch drive actuator torque. All LDDs consist of the respective load tables and the lists of applied DLCs including the number of occurrences.

(10) For the components of the blade pitching system, the root mean square value (RMS) of the 600 sec time series of the sensor “pitch actuator torque” is requested additionally for all load cases of DLC 1.1.

(11) For the tower and the foundation, the investigated load components shall be verified with a statement of the mean value and the amplitudes, e.g. through specification of the Markov matrices.

4.B.3 Further evaluations

(1) Maximum blade deflection and minimum tower clearance: In the case of wind turbines with a horizontal axis, the maximum blade deflection in the tower direction and the minimum clearance between the rotor blades and the tower or other parts of the turbine (determined for all load cases) shall be specified for the deformation analysis. Here the deformations of all blades shall be taken into account. The decisive load case shall be specified. See also Section 6.2.4.1, para 7.

(2) Maximum tower top acceleration: The maximum tower top acceleration in the tower longitudinal direction and in the tower lateral direction (x and y directions acc. to Fig. 4.A.5) shall be specified for the strength analysis. All load cases shall be considered. The acceleration values shall be multiplied with the partial safety factor for loads γ_F according to Tables 4.3.1 and 4.3.2.

(3) Maximum rotational speed: Statement of the maximum rotational speed of the rotor and generator n_{max} occurring for the entire load case simulation, and naming of the corresponding load case.

(4) Braking load cases: Graphic presentation of the time series of a braking load case with application of the mechanical brake or of the braking system bringing the turbine to standstill, in which the maximum torque occurs (rotor torque versus simulation time).
Statement of the maximum rotor braking time that is required when the mechanical brake is applied.

(5) Operation within the tower resonance range: If the wind turbine is operated within the tower resonance range (see Section 6.6.5.1), the corresponding evaluation and definition of the limiting values shall be submitted and explained.

(6) Design loads for locking devices: For the dimensioning of the locking devices for the blade pitching, rotor and yaw systems, the relevant loads shall be specified with consideration of the partial safety factors. This concerns the load cases DLC 8.1 and DLC 8.2.

(7) Design loads for appearance of a ground gap: In the case of slab foundations, the evaluation of load case combinations acting at the tower bottom shall be executed in tabular form in accordance with the specimen table for extreme load evaluation (see Table 4.B.1), including statement of the wind speeds and wind direction for the corresponding load situation. The essential load case combinations are given in Section 6.7.6, Table 6.7.1. For the analyses required in Section 6.7.6, Table 6.7.1, column 2 and Section 6.7.6.3 (4), the load case combinations listed in each case in column 1 shall be evaluated. In this evaluation, the partial safety factors may be applied with $\gamma_F = 1.0$ (analysis of the serviceability limit state). For the various load situations, the wind speeds and wind directions prevailing at that time shall be specified.

Table 4.B.1 Recommended presentation of the calculation results of extreme loads (F_{res} – resulting transverse force, M_{res} – resulting bending moment)

Results of the extreme load evaluation											
		Load case	γ_F	**Fx**	**Fy**	**Fz**	**Fres**	**Mx**	**My**	**Mz**	**Mres**
Fx	**Max**			▨							
	Min			▨							
Fy	**Max**				▨						
	Min				▨						
Fz	**Max**					▨					
	Min					▨					
Fres	**Max**						▨				
Mx	**Max**							▨			
	Min							▨			
My	**Max**								▨		
	Min								▨		
Mz	**Max**									▨	
	Min									▨	
Mres	**Max**										▨

Table 4.B.2 Recommended presentation of the calculation results of equivalent fatigue loads for various slope parameters of the S/N curve

Results of the fatigue load evaluation							
$\mathbf{n_{Ref}}$		**Fx**	**Fy**	**Fz**	**Mx**	**My**	**Mz**
Slope parameter of the S/N curve m	$\mathbf{m_a}$						
	$\mathbf{m_b}$						
	$\mathbf{m_c}$						
	$\mathbf{m_d}$						
	$\mathbf{m_e}$						
	$\mathbf{m_f}$						
	$\mathbf{m_g}$						
	$\mathbf{m_h}$						
	$\mathbf{m_i}$						
	$\mathbf{m_j}$						

Appendix 4.C Generator Short Circuit

(1) The loads of a generator short circuit can also be initiated by a short circuit in main parts of the internal electrical system. The worst case of a short circuit concerning the loads is in or near the generator or directly connected power circuits. Such short circuits shall be investigated, since this may result in very high transient loads. In the absence of any proven values that are more precise, the equations given below shall be applied.

(2) A two-phase short circuit generally leads to higher maximum torques than a three-phase short circuit, so that the two-phase case is decisive. A two-phase short circuit at the terminals of the synchronous generator, the following electromagnetic torque (M) shall be analysed:

$$M = \frac{1.3 \cdot M_n}{x''_d} \qquad (4.C.1)$$

where:

M_n = rated synchronous generator torque

x''_d = subtransient reactance of the synchronous generator per unit value, as stated by the generator manufacturer

If x''_d is unknown, the occurrence of 10.5 times the rated torque shall be taken into account.

If the synchronous generator is equipped with devices or measures for short circuit limitation, the resulting electromagnetic torque (M) shall be analysed by simulations. The generator model shall be submitted for assessment. Reference is made to Section 8.2.

(3) For a two-phase short circuit at the stator terminals of the induction generator, the following electromagnetic torque (M) shall be analysed:

$$M = -\frac{M_K}{1-\sigma} \cdot \cos\alpha + \frac{M_K}{1-\sigma} \cdot \cos\left(2\,\omega_g t - \alpha\right) - 2\,\frac{M_K}{1-\sigma} \cdot \sin\left(\omega_g t\right) \cdot e^{-\left(\frac{t}{T_1}\right)} \qquad (4.C.2)$$

where:

M_K = breakdown torque of the induction generator

σ = leakage coefficient

α = angle for two-phase short circuit with $\alpha = \arctan(\omega_g T_1)$

ω_g = angular frequency at the generator stator terminals

t = time

T_1 = time constant of the stator

The values M_K, σ and T_1 shall be applied in accordance with the information supplied by the generator manufacturer. If the required values are unknown, then 8 times the rated torque shall be taken into account.

(4) For induction generators, a three-phase short circuit shall also be investigated. Here the following electromagnetic torque (M) shall be analysed:

$$M = 2\,M_K \cdot \sin\left(\omega_g t\right) \cdot e^{\left(-2 s_K \omega_g t\right)} \qquad (4.C.3)$$

where:

ω_g = angular frequency at the generator stator terminals

M_K = breakdown torque of the induction generator

s_K = breakdown slip of the induction generator, as stated by the generator manufacturer

The maximum torque is attained when the following applies:

$$\omega_g\, t = \arctan\left(\frac{1}{2\,s_K}\right) \qquad (4.C.4)$$

Appendix 4.D Design Parameters for Describing Wind Turbine Class S

For class S wind turbines, at least the following design parameters shall be given in the design documentation:

4.D.1 Plant parameters

Rated power	[kW]
Operating wind speed range at hub height (V_{in} to V_{out})	[m/s]
Design lifetime	[a]

4.D.2 Wind conditions

Characteristic turbulence intensity as a function of the mean wind speed	[-]
Annual average wind speed at hub height	[m/s]
Average inclination of flow	[°]
Distribution function for the wind speed (Weibull, Rayleigh, measured, other)	
Wind profile model and parameters	
Turbulence model and parameters	
Extreme wind speeds V_{e1} and V_{e50} at hub height	[m/s]
Wind direction distribution (wind rose)	

4.D.3 Conditions of the electrical power network

Normal supply voltage and fluctuation	[V]
Normal supply frequency and fluctuation	[Hz]
Voltage imbalance	[V]
Maximum duration of electrical network outages	[d]
Number of electrical network outages	[1/a]
Auto-reclosing cycles (description)	
Behaviour during symmetrical and asymmetrical external faults (description)	

4.D.4 Other environmental conditions (where necessary)

Normal and extreme temperature ranges	[°C]
Humidity	[%]
Air density	[kg/m^3]
Intensity of the solar radiation	[W/m^2]
Rain, hail, snow and ice	
Chemically active substances	
Mechanically active particles	
Description of the lightning protection system	
Earthquake model and parameters	
Salinity	[g/m^3]

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IV Industrial Services

1 Guideline for the Certification of Wind Turbines

5 Strength Analyses

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Appendix 5.A

Appendix 5.B

5.1 General

(1) Components of a wind turbine shall be subjected to verification of their ultimate and serviceability limit states (as per Section 1.3.2.2). For this, the design loads (see Section 1.3.2.3) for the load cases determined according to Chapter 4 shall be applied.

(2) By strength is meant the resistance to loading of a component. It shall be verified in accordance with this section (see also the corresponding sections in Chapter 6). The strength depends on the material, on the shape of the loaded structure and on the type of loading (tension, compression, shear, bending, torsion).

(3) As a rule, analyses shall be performed by calculation. However, for fatigue analysis, component tests under simulated operating conditions are also permitted.

(4) Dynamic loading, such as resonance effects or impact forces, affecting the strain and stress levels of the wind turbine to an extent which cannot be disregarded shall be accounted for in a suitable manner (see also Sections 6.6 and 7.1).

(5) Local plastic and elastic deformation can adversely affect the functionality of a component. Both its function and that of the adjacent components shall be verified (e.g. bearings, gear box housings). The analyses to be made with regard to the limiting of deformation are described in detail in the relevant sections (e.g. Section 5.3.2 or 7.1).

(6) In addition to the guidelines listed below, further requirements for the analyses of the structures (rotor blades, forged, cast, welded structures, housings, tower and foundation, and bolted connections) and the special machinery components (e.g. gearbox, yaw systems, brakes, bearings, couplings and hydraulics), as given in Chapters 6 and 7, shall be observed.

5.2 Determination of the Stresses

5.2.1 General notes on the loading of the structure

(1) For the strength analyses, selected loading conditions which are decisive for the structural areas being analysed are considered as a rule. For assessments of fatigue strength, loading conditions which generate dynamic cyclic stresses at the critical regions shall be considered. The design situations (i.e. operating conditions) and design load cases are given in Section 4.3.3.

(2) Loads and loading conditions shall generally be treated in accordance with Chapter 4. More specific or especially adapted load criteria/values shall be well documented and agreed upon. The load cases and combinations to be considered in the design calculations shall cover the most unfavourable conditions likely to occur.

(3) Non-linearities in the load components shall, if relevant, be taken into account. For this, it shall be observed that the linear superposition principle does not apply here. In certain cases, forces which only arise for particular deformations (for example through the contact of structural areas) can be analysed in the form of additional load cases and superposed with consideration of the non-linear structural behaviour (e.g. radial compressive loads at the bearings).

(4) As an alternative to the approach using general strength analyses with selected load cases, special methods particularly suited to the complete consideration of the movements and loads (so-called time-series calculations) can be used.

(5) In calculations with time series, the loading or stressing process shall be generated from the characteristic data of the design load cases (cf. Section 4.3.3). The time series and the statistical frequencies for the structural analysis shall be chosen in accordance with Chapter 4. The validity of selected simplifications for the computational objective shall be documented in a plausible manner.

5.2.2 Method of analysis

5.2.2.1 General

(1) In general, the stress calculation may be carried out using conventional static theory. Where the decisive stresses cannot be established sufficiently accurately using these methods, calculations using numerical procedures (e.g. finite element method) shall be made.

(2) For the strength analyses, the effects resulting from loads acting on the components are usually determined as the stresses. At the failure-critical region, the nominal stress or the structural stress shall be determined according to the currently accepted rules of technology, as reflected in the applicable standards and codes. The selection of the failure-critical regions shall be documented.

(3) The use of modifications to the analysis procedures listed in the following shall be agreed with GL. Here it shall be ensured that a consistent analysis concept is applied.

(4) Further recommendations regarding the definition of objective, type and scope of a strength analysis as well as calculation and details on evaluation and documentation are also given in Appendix 5.A "Strength Analyses with the Finite Element Method".

5.2.2.2 Nominal stress approach

(1) The nominal stress is the stress determined by means of the elementary theories of linear elastic mechanics. Stress components from the notch effect are not included. They shall be considered through stress concentration factors (SCFs) and fatigue notch factors referred to the nominal stresses.

(2) The nominal stress concept is limited to slender bars and beams and to such structures which can be idealized with a close approximation as component details having a strip, bar or beam shape.

(3) In the case of fatigue analysis of non-welded components, S/N curves containing the detail categories or geometrical discontinuities to be considered shall be used. If in welded components there is a geometric discontinuity not covered by the selected allocation of the detail category to the design details, the nominal stress shall be modified (see e.g. [5.1], [5.2], [5.3]).

(4) In the case of combined types of stresses, Sections 5.3.3.2.4 and 5.3.3.3 shall be observed.

5.2.2.3 Structural stress approach

(1) Structural stress is understood as the stress which completely describes a stress condition. It includes effects from complex component shapes (spatially curved structures) and from design-related notches (e.g. grooves, steps, drill-holes) and local influences at load introduction. In welded structures, the structural stress is known as the “hot-spot stress” (see also [5.3] and Appendix 5.A). The term indicates that this structural geometric stress includes the influence of the nominal stress and local effects, but not the notch effect of the weld seam itself.

(2) In the case of fatigue analyses, material-dependent S/N curves shall be used for non-welded components if the structural stress includes all local influences of the notch effect. The fatigue verification shall be carried out by using S/N curves that correspond to the actual qualities of the component. The quality-related upgrading factors shall be chosen in accordance with the specified quality (e.g. j and j_0; see Section 5.3.3.5.3). If the quality is defined differently in specific areas of the component, it shall be assured that areas of different quality are covered by the analysis.

(3) Depending on the degree of discretization, it is necessary in the numerical calculations to consider a part of the notch effect which is not included in the structural stress, by reduction of the S/N curves.

(4) For welded joints, the hot-spot stresses (geometric stresses) are decisive in the fatigue analysis. When the structural hot-spot stress approach is used for the assessment of welded joints, the finite element modelling in terms of choice of element type and mesh quality shall be carried out in accordance with IIW recommendations [5.3]. Structural hot-spot stresses for the assessment of welded joints shall be calculated in accordance with IIW [5.3].

(5) In the case of combined types of stresses, Sections 5.3.3.2.4 and 5.3.3.3 shall be observed.

5.2.2.4 Influences

Influences that are based on the type of load, the geometry or the material shall be considered in the strength analyses. This also applies for non-linear influences

- of the loading (e.g. solely compressive loading for roller or sliding bearings), or
- the geometry (second order, linear theory; consideration of large deformations), or
- the material (plasticity theory and yield hinge theory).

5.2.3 Dynamic calculation

(1) With a dynamic calculation, the vibration-related system response of structures and components resulting from time-variant loads is determined with the influence of the structural dynamics of the entire wind turbine (cf. Chapter 4).

(2) The requirements for the dynamic calculations of the individual structures and components are given in the relevant sections of Chapters 6 and 7. With special regard for the vibration-oriented design of the tower, reference is made to Section 6.6.5.2.

5.2.4 Quasi-static calculation

(1) The loads for a quasi-static calculation include the influence of the structural dynamics of the entire wind turbine only to a certain degree. The missing dynamic components shall be taken into account through dynamic magnification factors (e.g. magnification factors such as the gust reaction factor; cf. Section 4.1.1, para 4).

(2) The requirements for the quasi-static calculations of the individual structures and components are given in the various sections of Chapters 6 and 7. With special regard for the quasi-static design of the tower, reference is made to Section 6.6.5.3.

5.3 Metallic Materials

The requirements which follow refer to metallic structures in general. Extended requirements are contained in Chapters 6 and 7 (e.g. verification of the ultimate and serviceability limit states of the tower and foundation in Sections 6.6 and 6.7).

5.3.1 Material properties

(1) Requirements, analyses and certificates for the materials of machinery components are treated in Chapter 3. Additional information is given in the following sections of this chapter.

(2) The material parameters shall be chosen on the basis of European or equivalent international codes in consultation with GL, e.g. EN 10025:2004 for hot-rolled products of structural steels.

5.3.2 Static strength analysis

5.3.2.1 General

(1) The general strength analysis shall be carried out on the basis of European or equivalent international codes in consultation with GL.

(2) Machinery components whose dimensioning is not covered by standard codes shall be designed and analysed according to the currently accepted rules of technology. For the dimensioning of bolted connections, the requirements set out in Section 6.5 shall be observed.

(3) Tower and foundation shall be verified according to Eurocode 3 or DIN 18800, with the relevant parts.

(4) The components shall be dimensioned with the design loads (see Section 1.3.2.3) with regard to the corresponding design strength (see Section 1.3.2.4).

(5) The partial material safety factor γ_M to be used as a basis for metallic components of all load case groups is

$$\gamma_M = 1.1$$

(6) The tower and the foundation shall be treated according to the uniform concept of partial safety factors for design loads (see Sections 6.6.1 and 6.7).

5.3.2.2 Method of analysis

(1) When performing the analysis, the general points of Section 5.2.2 shall be observed.

(2) The dimensioning of a structure or component depends primarily on the type of possible failure. If two or more types of loading occur simultaneously, the combined resulting stresses shall be assessed. As a rule, the ultimate limit state verifications shall be carried out with regard to the material and loading, using the following equivalent stress hypotheses.

(3) For ductile materials, the maximum shear strain energy hypothesis or the maximum shear stress hypothesis can be used. Other hypotheses, such as the shear stress intensity hypothesis, can be used as an alternative if adequate proof of their usefulness is given.

(4) For brittle materials (e.g. EN-GJS-700-2U), the behaviour of the material is described by the maximum principal stress hypothesis. In the case of semiductile materials (e.g. EN-GJS-400-18U-LT), either the maximum principal stress hypothesis or the maximum shear strain energy hypothesis (e.g. von Mises) can be applied.

(5) Other hypotheses can be used as an alternative if their applicability is ensured by adequate component tests.

(6) Minor plastification, limited to local notches, is usually permissible for components made of ductile and semiductile materials. If, for structures consisting of such materials, the local stress values are located above the elastic limit (start of yielding), it shall be observed that the local stress distribution and thus the local strains have to be considered for assessment of the static component strength. Here it must be taken into account that the local stress and strain distribution depends both on the component shape (e.g. notch) and on the type of loading (tension/compression, bending, torsion). The total permissible notch base strain may not exceed 1.0 % for ductile (e.g. S235 J2+N) and semiductile materials (e.g. EN-GJS-400-18U-LT). In all cases, this is limited to minor plastifications, resulting from extreme load cases at local notches.

(7) In addition, the permissible strain depends on the function of the structure, so that, in the case of permanent elongation, proof of operativeness shall be given for the component and its adjacent components. The procedure shall be defined in consultation with

GL. For tower and foundation, the design yield stress f_{yd} shall not be exceeded by more than 10 % as a rule.

(8) Any plastifications in combination with failure-critical areas of the component (e.g. areas subjected to high fatigue stressing) should be avoided. The superposition of local plastification limited to notched areas with fatigue critical areas can be accepted, provided that the design lifetime will not be harmed. The influence shall be evaluated by adequate means.

5.3.3 Fatigue analysis

5.3.3.1 General

(1) In the following, components under variable cyclic loading are referred to as “dynamically loaded”.

(2) For the predominantly dynamically loaded metallic components of wind turbines, a fatigue analysis shall be carried out. As a rule, this applies to the drive-train components from the blade connection to the generator, the main frame including its connection to the tower, the generator frame, the tower including its connection to the foundation, the connecting elements and other turbine-specific components (e.g. blade pitch mechanism).

(3) The fatigue analysis may be carried out by component testing, computational analyses or analytical analysis, if applicable. Component tests shall be carried out with loads relevant to operation and using Chapter 4 as a basis. Evaluation of the test results shall be such that the effects of those influences which cannot be taken into consideration directly (large number of load cycles > 10^9, scattering of the test results etc.) are reliably covered; see [5.2]).

(4) The analysis of adequate fatigue strength, i.e. the resistance against crack initiation under dynamic operational loads, serves the assessment and reduction of the crack initiation probability of components within the scope of the structural design. Owing to incalculabilities in the loading process, involving material- and production-related variances and ageing effects, crack initiation in later operation cannot completely be ruled out, necessitating measures such as periodical inspections and other appropriate actions.

(5) The technical crack initiation shall be taken as a general failure criterion, i.e. a crack that is detectable on site with the usual non-destructive inspection methods.

(6) In special cases, the remaining lifetime of an initiated crack that is growing steadily may, in consultation with GL, be used for limited continued operation of a wind turbine. For this, the remaining lifetime shall be verified with suitable and recognized analysis methods. In addition, periodical inspections at appropriate intervals shall be laid down in consultation with GL.

5.3.3.2 Methods for fatigue analysis

5.3.3.2.1 General

(1) Depending on the required computational accuracy, fatigue analysis by calculation may be performed with the aid of one of the following three procedures:

- by using stress-time series and damage accumulation to register the complex interaction between the external loadings and the structural responses as accurately as possible, or
- by using stress spectra and damage accumulation. The superposition of the various load effects shall include the worst physical meaningful combination.
- with equivalent constant-range spectra as a simplified form of the fatigue analysis. Here the equivalent constant-range spectra shall be used in accordance with Section 4.B.2.3.

(2) The procedure and the applied loads shall be documented adequately (see Appendix 5.A.5).

(3) Tower and foundation shall be verified according to EN 1993-1-9:2005.

(4) If not defined otherwise in referenced standards, the influence of the mean stress shall be considered in accordance with Section 5.3.3.4.

(5) For complex components subjected to combined loading (see Fig. 5.3.1), adequate procedures for the hot-spot localization shall be applied. In general, stress-time series shall be used and the entire component must be analysed.

5.3.3.2.2 Simplified fatigue analysis

(1) For the simplified fatigue analysis, which is generally applied when considering safety margins by stress reserve verification (e.g. comparison of plant variants with different rotor diameters), equivalent constant-range spectra can be used. In the following, it will be assumed that the elaboration of equivalent constant-range spectra on the basis of the Palmgren/Miner method is already known. Explanations on this method can be taken from e.g. [5.2].

(2) When generating the equivalent constant-range spectrum, the slope parameter of the S/N curve corresponding to the material used shall be applied. The decisive slope parameter of the design S/N curve is given in Section 5.3.3.5.

(3) In this and the other analysis approaches, the partial safety factor γ_M shall be applied in relation to the criteria given in Table 5.3.1.

(4) For the stress superposition in the case of multi-axial stress conditions, see Section 5.3.3.2.4.

(5) When using the simplified fatigue analysis for considering safety margins, it shall be observed that the assumed reference load cycle number generally does not correspond to the assumed design lifetime of the component.

(6) Reducing influences on the fatigue resistance (such as probability of survival $P_ü$, surface influence etc.) shall be taken into account analogously to the determination of the S/N curves according to Section 5.3.3.5.

Note:

By way of example, instances for the application of the partial safety factor γ_M are named in Table 5.3.2 for fatigue analyses which normally apply according to the criteria listed in Table 5.3.1 for the force- and moment-transmitting components of a wind turbine to be considered here.

Table 5.3.1 Partial safety factor γ_M for fatigue verification

Inspection and accessibility	***Component failure results in destruction of wind turbine or endangers people***	***Component failure results in wind turbine failure or consequential damage***	***Component failure results in interruption of operation***
Periodic monitoring and maintenance; good accessibility	*1.15*	*1.0*	*1.0*
Periodic monitoring and maintenance; poor accessibility	*1.25*	*1.15*	*1.0*

Table 5.3.2 Example for the partial safety factor γ_M

Penetrations for reinforcing steel in the foundation section	*Cannot be inspected*	$\gamma_M = 1.25$
Bearing collar of the rotor shaft	*Cannot be inspected without removing the shaft*	$\gamma_M = 1.25$
Planet carrier of main gearbox	*Cannot be inspected; failure can lead to destruction of wind turbine*	$\gamma_M = 1.25$
Bolted connection of hub/rotor shaft (multiple bolt connection)	*A single bolt failure in a multiple bolt connection can be detected before complete failure of the connection*	$\gamma_M = 1.15$
Fixture for control cabinets Fixture of accumulators	*Operation of wind turbine will be interrupted*	$\gamma_M = 1.0$

5.3.3.2.3 Damage calculation

(1) The execution of fatigue verifications via damage accumulation will hereunder be assumed to be known. Explanations of this method may for instance be taken from [5.1], [5.2].

(2) When working out a damage accumulation, all stress ranges $\Delta\sigma_i$ due to operational loads in accordance with Chapter 4 shall, as a matter of principle, be used in conjunction with their associated stress cycle numbers n_i. The damage sum D from the fatigue strength calculation is dependent on the material, type of loading and structural geometry. The damage sum may not exceed the following values:

$$D \le 1$$

In case of welded machinery components that are subjected to variable amplitude loading, the damage sum may not exceed

$$D \le 0.5$$

e.g. when using the Palmgren/Miner linear damage accumulation hypothesis:

$$D = \sum_i n_i / N_i \le D_{admi}$$

where:

n_i = number of stress cycles in one bin of stress ranges

N_i = number of tolerable stress cycles in one bin of stress ranges

(3) The number of tolerable stress cycles N_i is here the permissible number of stress cycles of the relevant S/N curve for the stress range $\Delta\sigma_i \cdot \gamma_M$.

(4) The partial safety factor γ_M is given in Table 5.3.1.

(5) For the damage accumulation, the design S/N curves given in the paragraphs that follow (see Section 5.3.3.5) and the equivalent stresses described in Section 5.3.3.3 shall be used.

(6) For stress superposition in the case of multi-axial stress conditions, see Section 5.3.3.2.4.

5.3.3.2.4 Notes on the superposition of multi-axial stress conditions

(1) For multi-axially stressed components (see Fig. 5.3.1), it is necessary to consider the complex stress conditions in a realistic manner and to prepare them for the damage accumulation calculation in a physically meaningful manner. For this, the relevant time series of the fatigue loads are applied in accordance with Chapter 4.

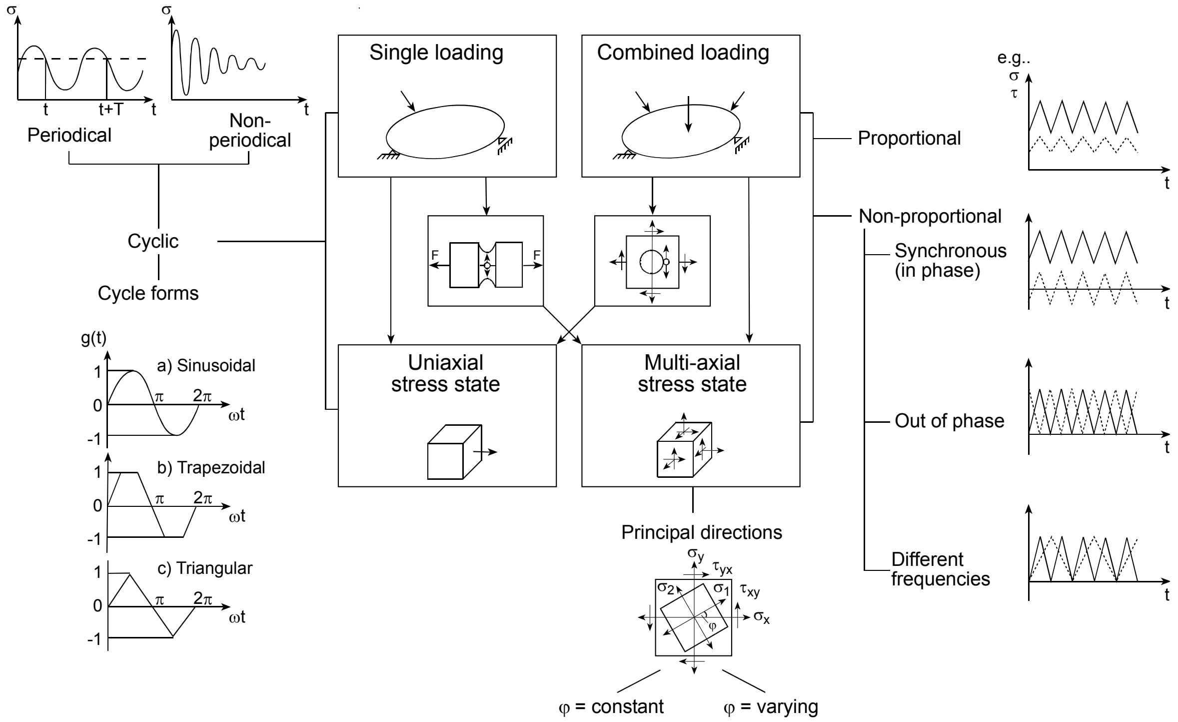


Fig. 5.3.1 Relationship of various terms in the field of multi-axialities according to Liu/Zenner

(2) When analysing multi-axial stresses, it is recommended that the dominating (damage-relevant) stress distribution or stress combination be established for the critical regions via consideration of the principal stresses and principal-stress directions. Occasionally, the presence of a dominating load component, or the combination of load components, may lead to a stress condition that is close to uni-axial. In such cases, this may allow a possible simplification that is appropriate for the problem.

(3) If the nominal stress approach is chosen for the assessment of welded joints and if normal and shear stresses occur simultaneously, their combined effect shall be considered in accordance with [5.1] or [5.3].

(4) If the structural stress approach is chosen for the assessment of welded joints, principal stresses shall be analysed. In cases where the direction vector of the principal stress is approximately in line with the perpendicular to the weld seam and does not change significantly over time, this stress may be used in combination with the fatigue resistance values in accordance with [5.1] or [5.3]. If the direction vector varies significantly, the other principal stresses need to be analysed as well. Their combined effect shall be considered in accordance with [5.3].

(5) The applicable procedure depends on the material, the type of loading and structural geometry, and shall be defined in consultation with GL.

5.3.3.3 Equivalent stress hypotheses

(1) In cases of multi-axial stress conditions, the fatigue-relevant stress components (also as time series) shall be transformed to a mono-axial stress condition by means of an adequate equivalent stress hypothesis.

(2) For ductile materials, an equivalent stress hypothesis (e.g. maximum shear strain energy hypothesis, maximum shear stress hypothesis) can be applied as a method of the critical plane. Other hypotheses, such as the shear stress intensity hypothesis for ductile materials, can be used as an alternative, provided that adequate proof of their usefulness is given.

(3) For brittle and semiductile materials (e.g. EN-GJS-400-18U-LT belongs to the semiductile materials), the normal stress hypothesis can be applied as a method of the critical plane. Other hypotheses have to be used if it can be predicted that the component will fail due to the effects of other kinds of stresses.

(4) If the nominal stress approach is chosen for the assessment of welded joints, the decisive stresses are those transverse or parallel to the weld seam. If normal and shear stresses occur simultaneously in welded joints, their combined effect shall be considered in accordance with [5.1] or [5.3].

(5) If the structural stress approach is chosen for the assessment of welded joints, the principal stresses are decisive. If the direction vectors of the principal stresses vary significantly, the combined effect of these stresses shall be considered in accordance with [5.3].

The procedure used shall be defined in consultation with GL.

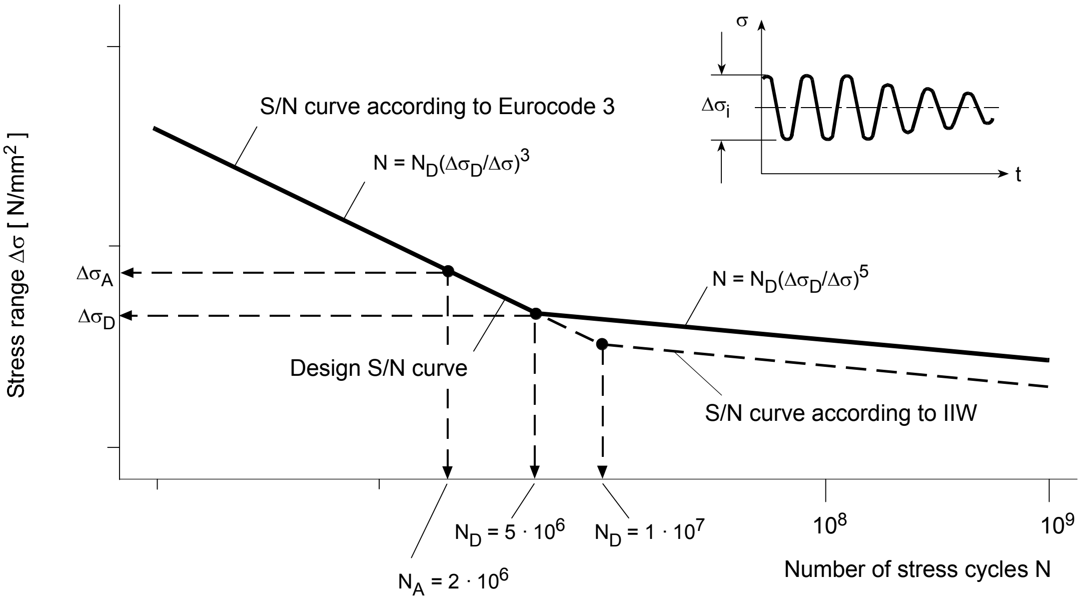


Fig. 5.3.2 S/N curve for welded structures, general shape

5.3.3.4 Mean stress correction

(1) In general, the material's fatigue strength is sensitive to mean stresses. The influence of the mean stress has to be considered by means of Haigh diagrams (cf. Fig. 5.3.3).

(2) An additional mean stress correction is not necessary if the correction is already considered within the detail category.

(3) When using stress-time series for the fatigue analysis, the damage-equivalent amplitude $\sigma_A^*(R)$ corresponding to a S/N curve of the same stress ratio R has to be calculated for each given combination of stress amplitude σ_A^* and mean stress σ_m.

(4) Alternatively, the S/N curve may be adjusted in a corresponding manner.

(5) If stress spectra or equivalent constant-range spectra are used (cf. Section 5.3.3.2.1), the influence of the mean stress shall be considered in a demonstrably conservative manner.

(6) The conversion of stress amplitudes is to be carried out by one or two lines parallel to the fatigue life line in the Haigh diagram (cf. Fig. 5.3.3).

(7) The mean stress sensitivity M has to be chosen depending on the material. For cast iron, the mean stress sensitivity M has to be used for $-\infty \leq R \leq 1$. In case of ductile steel materials, a slope M/3 may be applied for $0 \leq R \leq 1$. Other methods shall be agreed with GL in advance.

(8) The procedure of mean stress correction depicted in Appendix 5.B is applicable as well.

(9) In general for welded components, positive effects from mean stress corrections may only be applied if no significant residual stresses occur (e.g. after post-weld heat treatment).

(10) The limiting stress level is defined by the admissible yield stress (e.g. $R_{p0.2}$ / γ_M). The occurring mean stress plus the stress amplitude σ_a shall not exceed the limiting stress level (σ_m+σ_a <= σ_{lim}).

5.3.3.5 S/N curves for dimensioning

5.3.3.5.1 S/N curves for welded steel structures and bolted connections

(1) The selection of the S/N curves follows e.g. EN 1993-1-9:2005 [5.1] or IIW Recommendations [5.3]. Detail category selection shall be in accordance with Eurocode 3 (EC 3) [5.1] for towers and foundations and IIW Recommendations [5.3] for machinery structures or equivalent codes. Application of equivalent codes is permissible in consultation with GL.

(2) Reducing influences, e.g. because of the material thickness or insufficient alignment of the two joints to be welded, shall be observed in accordance with EC 3 [5.1] or IIW [5.3].

(3) In deviation from EN 1993-1-9:2005, the thickness correction shall be applied in accordance with IIW [5.3] when applying the structural stress approach.

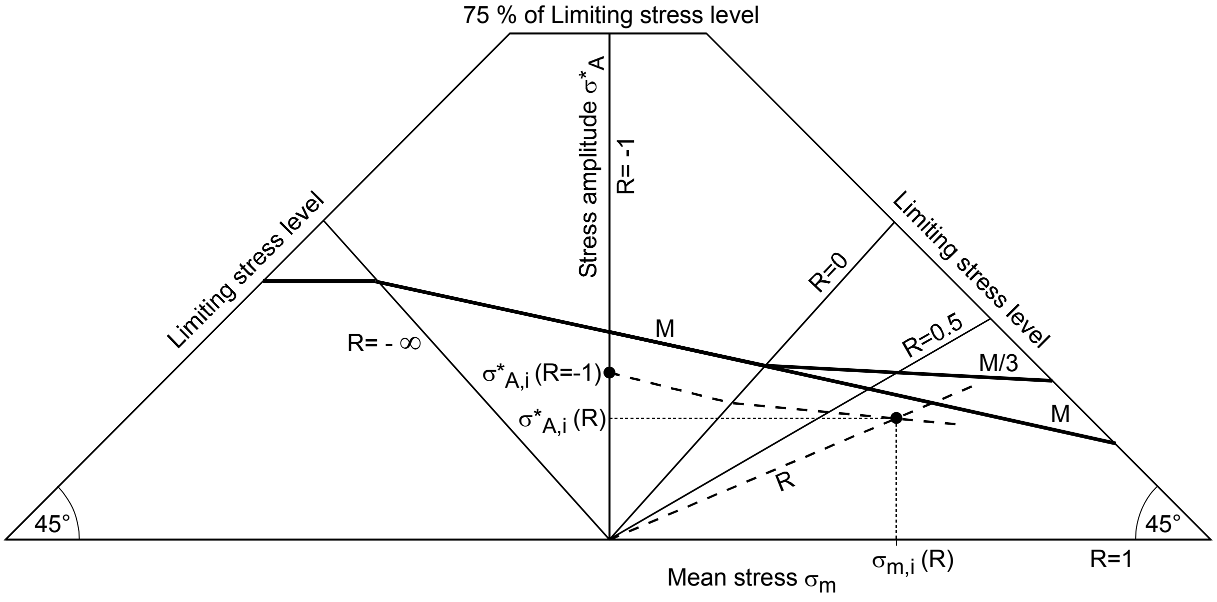


Figure 5.3.3 Haigh diagram

(4) Post-weld improvement techniques have to be accepted by GL (see Section 3.4.2.7).

(5) For welded machinery components that are stressed by predominantly variable stress ranges $\Delta\sigma_i$, fatigue verification is usually carried out using damage accumulation with the stress ranges in accordance with Chapter 4 as a basis. The damage sum D may not exceed the value of 0.5:

$$D \le 0.5$$

(6) S/N curve according to EN1993-1-9:2005

In the case of loading by normal stresses, the following additional agreement applies to the S/N curve as per EN1993-1-9:2005:

- region I:
  slope parameter of the S/N curve $m_1 = 3$, stress cycle numbers $N_i < 5 \cdot 10^6$
- region II:
  slope parameter of the S/N curve $m_2 = 5$, stress cycle numbers $N_i \ge 5 \cdot 10^6$

For predominantly shear-stress loaded components, the S/N curves of EN 1993-1-9:2005 shall be used with a constant slope parameter m = 5:

- region I + II:
  slope parameter of the S/N curve m = 5

(7) S/N curve according to IIW Recommendations

When machinery structures are assessed, the following applies to the S/N curve:

- region I:
  slope parameter of the S/N curve $m_1 = 3$, stress cycle numbers $N_i < 1 \cdot 10^7$
- region II:
  slope parameter of the S/N curve $m_2 = 5$, stress cycle numbers $N_i \ge 1 \cdot 10^7$

(8) In all cases, a threshold value of the fatigue strength (cut-off) is not permissible. Fig. 5.3.2 shows the general shape of the S/N curve to be used as a basis.

(9) When establishing the tolerable number of stress cycles N_i (see Section 5.3.3.2.3), account shall be taken of the partial safety factors γ_M according to Table 5.3.1.

(10) The fatigue strength line of the S/N curve shall be limited by the elastic properties of the base material including the partial safety factor for material γ_M. The respective mean stress level shall be considered when determining the upper limit of the fatigue strength line.

(11) When analysing the fatigue strength of bolted connections, whose stress levels are established under consideration of the tension and bending in the bolt, the following detail categories are permissible up to the size M30 (metric standard thread):

- hot-dip galvanized bolts rolled before heat treatment:
  detail category 50
- bolts rolled before heat treatment:
  detail category 71
- bolts rolled after heat treatment:
  detail category $71*(2-\frac{F_{S\max}}{F_{0,2\min}}) \le 85$

  where:

  $F_{S\max}$ = max. bolt force under extreme load

  $F_{0,2\min}$ = bolt force at the 0.2 % elastic strain limit

The S/N curve for bolts shall be assumed according to EN 1993-1-9:2005.

(12) Here the dimensioning-relevant cross-section A is the stress cross-section A_S in the thread. The influence of the reduction in cross-section can usually be neglected for hot-dip galvanized parts.

(13) For bolts larger than M30, a reduction of the S/N curve by the factor k_s with

$$k_s = (30\text{mm}/d)^{0,25}$$

shall be taken into account, where d is the nominal diameter. Further requirements on bolt dimensioning are given in Section 6.5.

5.3.3.5.2 S/N curves for the design of non-welded forged and rolled parts

(1) Selection

On principle, statistically assured S/N curves for the raw material should be used as a basis. Requirements for material testing have to be defined in consultation with GL. If such S/N curves are not available for the steels to be used, synthetic S/N curves in accordance with Appendix 5.B may be used for a comprehensive fatigue analysis (damage calculation in accordance with Section 5.3.3.2.3).

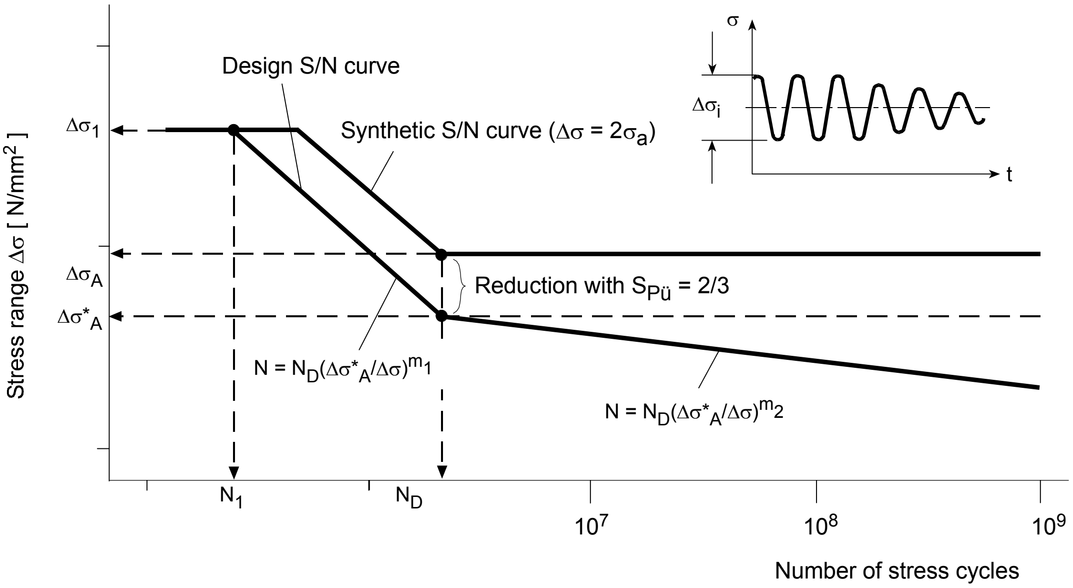


Fig. 5.3.4 S/N curve for non-welded forged and rolled parts, example "Synthetic S/N curve"; general shape

(2) Reducing influences

The following reducing influences on the fatigue resistance shall be considered (e.g. Appendix 5.B or [5.4]):

- type of loading
- stress ratio
- stress concentration factor
- notch effect factor
- component size
- surface influence
- influence of technological parameters
- survival probability
- environmental conditions (corrosion etc.)

(3) Survival probability

Usually, S/N curves are assigned a survival probability of $P_Ü = 50$ %, see e.g. [5.4]. The fatigue analysis shall be performed with a survival probability of $P_Ü > 97.7$ %. Unless determined otherwise, the S/N curve reference value $\Delta\sigma_A$ shall be reduced to

$$\Delta\sigma^*_A = \Delta\sigma_A \cdot S_{Pü} \qquad \text{where } S_{Pü} = 2/3$$

which corresponds to a survival probability of $P_Ü > 97.7$ % (mean value $- 2 \cdot$ standard deviation). If S/N curves with a survival probability of $P_Ü > 50$ % are used, a reduction factor $S_{Pü} > 2/3$ may be assumed after consultation with GL.

(4) Admissible stress range

The fatigue strength line of the S/N curve shall be limited by the elastic properties of the material including the partial safety factor for material γ_M. The respective mean stress level shall be considered when determining the upper limit of the fatigue strength line.

(5) Stress cycle numbers

For stress cycle numbers $N_i > N_D$, the S/N curves shall be extended from $\Delta\sigma^*_A$ with the slope parameters $2m_l$-1, where m_l is the slope parameter of the fatigue strength line (see Fig. 5.3.4). Here the limiting stress cycle number N_D is that number at which, under optimum test conditions (no corrosion effect etc.), the endurance limit is given. Where synthetic S/N curves are used, N_D results from its calculation.

5.3.3.5.3 S/N curves for the design of cast steel and spheroidal graphite cast iron

(1) Selection

On principle, statistically assured material S/N curves shall be used. Requirements for material testing have to be defined in consultation with GL. If such S/N curves are not available for the cast material to be used, synthetic S/N curves in accordance with Appendix 5.B may be used as a basis for a comprehensive fatigue analysis (damage accumulation calculation in accordance with Section 5.3.3.2.3).

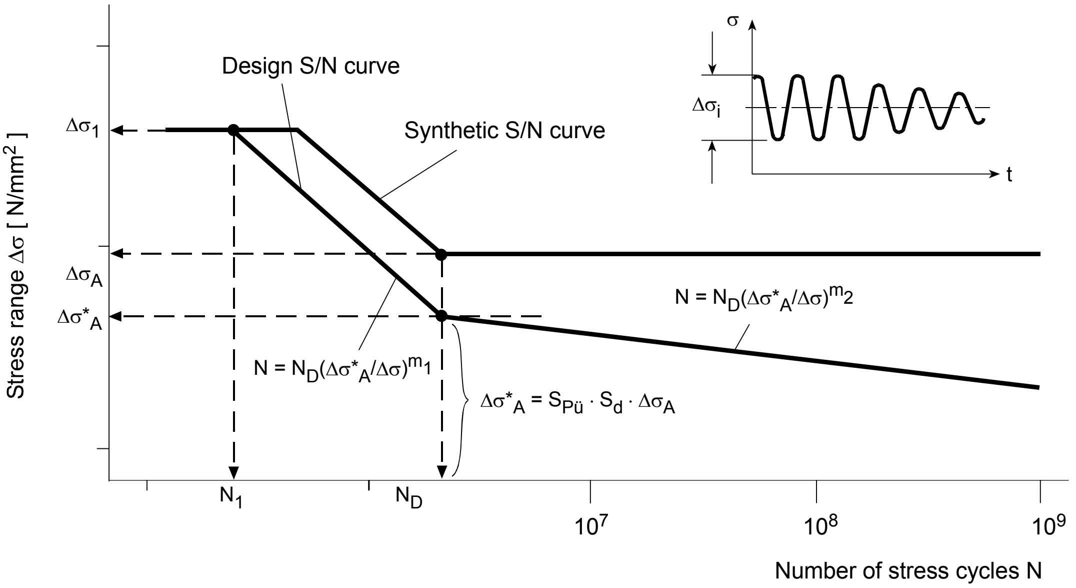


Fig. 5.3.5 **S/N curve for cast steel and spheroidal graphite cast iron, example "Synthetic S/N curve"; general shape**

(2) Reducing influences

The following reducing influences on the fatigue resistance shall be considered (e.g. Appendix 5.B):

– type of loading

– significant residual stresses (e.g. shot peening)

– stress ratio

– stress concentration factor

– notch effect factor

– component size

– surface influence

– influence of technological parameters

– survival probability

– environmental conditions (corrosion etc.)

(3) Survival probability

Usually, S/N curves are assigned a survival probability of $P_Ü$ = 50 %. For the fatigue analysis, the S/N curve reference value $\Delta\sigma_A$ shall be reduced to

$$\Delta\sigma^*_A = \Delta\sigma_A \cdot S_{Pü} \qquad \text{where } S_{Pü} = 2/3$$

which corresponds to a survival probability of $P_Ü > 97.7$ % (mean value – 2 · standard deviation). If S/N curves with a survival probability $P_Ü > 50$ % are used, a reduction factor $S_{Pü} > 2/3$ may be assumed after consultation with GL.

(4) Admissible stress range

The fatigue strength line of the S/N curve shall be limited by the elastic properties of the material including the partial safety factor for material γ_M. The respective mean stress level shall be considered when determining the upper limit of the fatigue strength line.

(5) Reduction factors

The influence of large wall thicknesses and surface roughness shall be taken into account. In the case of S/N curves determined from specimens taken from equally thick component regions, the influence of large wall thickness is included in the S/N curves. When determining synthetic S/N curves (see Appendix 5.B), both the thickness-dependent mechanical characteristic values (guaranteed minimum tensile strength and yield point) as well as the reduction through the existing surface roughness shall be observed.

(6) In using synthetic S/N curves, the influence of the quality levels (cf. Section 3.3.2.2 and 3.3.2.5) shall be considered through the factor

$$S_d = 0.85^{(j-j_0)}$$

where

j = the quality level for the component or component detail to be designed with adequate fatigue strength
(1...3; cf. Sections 3.3.2.2 and 3.3.2.5)

j_0 = constant depending on the test method (0 or 1), with the following values:

Ultrasonic (UT) or radiographic (RT) inspection	j_0=0
Additional testing Liquid penetrant (PT) or magnetic particle (MT) surface inspection	j_0=1

For the assessment of the casting and surface quality and the testing techniques to be applied, the requirements listed in Sections 3.3.2.2 and 3.3.2.5 shall be observed. MT/PT quality level is limited to level 3 in general. For the UT quality level 1 area, MT/PT quality level will be limited to level 2. This will ensure that, in the UT quality level 1 area, the more critical surface flaws detected by MT/PT are not allowed to be bigger than internal flaws detected by UT.

(7) The classification into quality levels shall be documented consistently in the drawings, calculations and specifications and submitted to GL for assessment within the scope of the Design Assessment and Implementation of the design requirements in Production and Erection or of surveillance during production (cf. Sections 1.2.2.4.2 and 1.2.3.5). The requirements of Section 3.3.2.2 (cast steel) and Section 3.3.2.5 (cast iron) shall be observed.

(8) Design S/N curve

The reference stress range to be used as a basis for the S/N curve is

$$\Delta\sigma^*_A = S_{Pü} \cdot S_d \cdot \Delta\sigma_A$$

as the ideal fatigue limit at the stress cycle number N_D (see Fig. 5.3.5). For stress cycle numbers $N_i > N_D$, the S/N curves shall be extended from $\Delta\sigma^*_A$ with the slope $2m_l$-1, where m_l is the slope parameter of the fatigue strength line (see Fig. 5.3.5).

5.3.3.5.4 S/N curves for the design of aluminium parts

(1) On principle, statistically assured S/N curves shall be used.

(2) For detail categories, the detail category selection shall be in accordance with [5.3]. In cases of doubt, the procedures shall be agreed with GL .

5.3.4 Serviceability analysis

5.3.4.1 Partial safety factors

For verifications in the serviceability limit states, the partial safety factor shall be γ_M = 1.0.

5.3.4.2 Deformation analysis

If no special requirements arise from life cycle (e.g. operation and maintenance) of the plant, a limitation of deformations is not necessary (see also Section 5.3.2.2, para 6).

Note:

Plastification of the rotor lock under extreme load shall be avoided, otherwise functionality of the rotor lock system can be restricted or fail.

5.4 Concrete

5.4.1 Material properties

5.4.1.1 Characteristic values

(1) The material parameters required for the analysis of concrete, reinforcing steel and prestressing steel are found in Eurocode 2, Section 3, or DIN 1045-1, Section 9.

(2) It shall be assured that the materials used for construction on site comply with the standards used for calculation and with the specification on the design drawings.

5.4.1.2 Partial safety factors γ_M

The design resistance shall be determined with due consideration of the partial safety factors γ_M according to Table 5.4.1. For calculations of deformations within the scope of second order theory for towers made of reinforced and prestressed concrete, $\gamma_M = 1.2$ may be assumed for the modulus of elasticity of concrete.

5.4.2 Ultimate limit states

5.4.2.1 Fracture and stability failure

(1) Analysis of components made of reinforced concrete or prestressed concrete shall be based on the uniform concept of partial safety factors for design loads (see Section 1.3.2.3).

(2) The analyses shall be performed with the most unfavourable of all the combinations of actions of groups N, A and T according to Section 4.3.3, Tables 4.3.1 and 4.3.2.

(3) For the analysis of reinforced concrete and prestressed concrete, Eurocode 2 or DIN 1045-1 shall be applied. Exceptions from the a.m. standards shall be agreed with GL. The safety level of the a.m. standards shall be fulfilled in any case.

(4) The increase in the internal forces and moments through non-linear influences (e.g. second order theory, crack formation) shall be taken into account. It may be determined from a quasi-static calculation.

(5) In the case of prestressed components, the influences of creep, shrinkage and relaxation shall be considered.

(6) Zones of concentrated load introduction shall be investigated in detail.

5.4.2.2 Fatigue analysis

(1) For components of reinforced concrete or prestressed concrete, detailed fatigue analysis shall be provided for the concrete, the reinforcing steel and the prestressing steel with the loads of group F. The verification shall be performed by means of load spectra and corresponding mean values or Markov matrices. CEB-FIP Model Code 1990 [5.5 a/b], Section 6.7.4 and 6.7.5, or equivalent shall be applied for fatigue verification.

(2) For wind turbines with a nominal number of operational load cycles

$$N_{\mathrm{nom}} = r \cdot n_{\mathrm{R}} \cdot T \leq 2 \cdot 10^{9} \qquad (5.4.1)$$

where:

r = number of rotor blades

n_{R} = rated rotor speed

T = intended service life

a detailed analysis for concrete under compressive loading is not required, if the condition expressed in following equation 5.4.2 is met:

$$S_{\mathrm{cd,max}} \leq 0.40 + 0.46 \cdot S_{\mathrm{cd,min}} \qquad (5.4.2)$$

Table 5.4.1 Partial safety factors for the material γ_M

Material	Ultimate limit state		Serviceability limit state
	Fracture and stability failure	Fatigue	
Concrete	1.5 [1] (1.2) [2]	1.5	1.0
Spun concrete	1.4 [1] (1.2) [2]	1.4	1.0
Reinforcing and prestressing steel	1.15 [1]	1.15	1.0

[1] For unusual design situations, e.g. earthquake calculations, $\gamma_M = 1.3$ can be set for concrete and spun concrete and $\gamma_M = 1.0$ for reinforcing steel and prestressing steel.

[2] For the calculation of deformations when taking account of non-linearities of the geometry and/or the material, $\gamma_M = 1.2$ may be taken (value in brackets).

[3] For precast concrete elements, a reduction of the partial safety factor for concrete γ_M is allowable if this reduction is given in the recognized design code used (EC 2 or DIN 1045-1). In this case, the conditions of the code for the reduction shall be fulfilled. Required measures shall be specified in consultation with GL. Mixing of the two codes is not permitted.

with:

$S_{cd,min} = \gamma_{Sd} \cdot \sigma_{c,min} \cdot \eta_c / f_{cd,fat}$

$S_{cd,max} = \gamma_{Sd} \cdot \sigma_{c,max} \cdot \eta_c / f_{cd,fat}$

where:

γ_{Sd} = 1.1 – partial safety factor to consider the inaccuracies of the model for stress calculation

$\sigma_{c,max}$ = magnitude of the maximum concrete compressive stress, with the combinations of actions of group F according to Section 4.3.3, Tables 4.3.1 and 4.3.2

$\sigma_{c,min}$ = magnitude of the minimum concrete compressive stress in the pressure zone at the same position at which $\sigma_{c,max}$ occurs, determined by the lower value of the action effect (for tensile stresses, $\sigma_{c,min} = 0$ shall be set)

η_c = factor for considering the non-uniform distribution of the concrete compressive stresses as per DAfStb booklet 439, equation (8); as a simplification, $\eta_c = 1.0$ may be set.

$f_{cd,fat}$ = $0.85 \cdot \beta_{cc}(t) \cdot f_{ck} \cdot (1 - f_{ck}/250) / \gamma_c$; design value of the fatigue strength of the concrete under compressive loading

with:

f_{ck} = characteristic cylinder compressive strength in N/mm²

γ_c = partial safety factor for concrete (see Table 5.4.1)

$\beta_{cc}(t)$ = coefficient for considering the time-dependent strength increase in the concrete. Here $ß_{cc}(t)$ shall not be set larger than 1.0, corresponding to a cyclic initial loading with a concrete age ≥ 28 days. In the case of cyclic initial loading at an earlier age of the concrete, $ß_{cc}(t) < 1.0$ shall be determined and taken into account in the analysis.

(3) On principle, the following shall be investigated for the simplified analysis procedure according to 5.4.2.2, para 2:

- maximum load range
- load range with the largest concrete compressive stress $\sigma_{c,max}$
- load range with the smallest concrete compressive stress $\sigma_{c,min}$
- load range with the largest mean value for the concrete compressive stress

The damage components of the load effects from erection conditions without the machine shall be considered in accordance with Section 6.6.6.1.5.

5.4.3 Serviceability limit state

5.4.3.1 Partial safety factors

For verifications in the serviceability limit states, the partial safety factor shall be $\gamma_M = 1.0$.

5.4.3.2 Deformation analysis

If no special requirements arise from operation of the turbine, a limitation of deformations is not necessary.

5.4.3.3 Stress limitation

(1) For towers of reinforced concrete and prestressed concrete, the concrete compressive stresses for the rare combination of actions DLC 1.5, 1.6 and 9.4 shall be limited to $0.6\,f_{ck}$. Otherwise substitute measures, e.g. according to DIN 1045-1:2008-08, 11.1.2 (1), shall be taken.

(2) In addition, for towers of prestressed concrete, the concrete compressive stresses under constant loads (own weight and prestressing) shall be limited to $0.45\,f_{ck}$.

5.4.3.4 Crack control

(1) For components of prestressed concrete with bond, the verification of decompression shall be provided for the quasi-permanent combination of actions DLC 1.1 and 6.4 with a probability of exceedance of $p_f = 10^{-2}$ (equivalent to 1750 h in 20 years). The verification of decompression shall be provided even for the frequent combinations of actions DLC 1.5 and 9.4 for these components when they are exposed to environmental conditions with corrosion induced by chlorides (e.g. structures near to or on the coast).

Note:

For the quasi-permanent combination of actions, the actions DLC 1.1 and 6.4 which occur more than 10^4 times are recommended as a conservative alternative.

(2) Verification of crack width limitation shall generally be provided for a theoretical crack width of 0.2 mm. For components of reinforced concrete and prestressed concrete without bonding, the quasi-permanent combination of actions DLC 1.1 and 6.4 with a probability of exceedance of $p_f = 10^{-2}$ (equivalent to 1750 h in 20 years) shall be used. For components of prestressed concrete with bond in normal environmental conditions, the frequent combinations of actions DLC 1.5 and 9.4 shall be used for crack width limitation. For components of pretensioned concrete with bond in environmental conditions with corrosion induced by chlorides, the rare combination of actions DLC 1.5, 1.6 and 9.4 shall be used. For these verifications, the heat influences as per Section 4.2.4.1 shall be applied.

5.4.3.5 Load-dependent stiffness reduction

(1) For towers of reinforced and prestressed concrete, load-dependent stiffness reduction due to cracking (state 2 of reinforced concrete sections) shall be taken into account for the calculation of the natural frequencies of the tower. For this calculation, stabilized cracking conditions shall be assumed for the complete tower. Moment-curvature diagrams shall be provided.

(2) The verification of load-dependent stiffness reduction can be omitted for the calculation of the natural frequencies when decompression is verified for the quasi-permanent combination of actions DLC 1.1 and 6.4 with a probability of exceedance of $p_f = 10^{-2}$ (equivalent to 1750 h in 20 years).

Note:

For the quasi-permanent combination of actions, the actions DLC 1.1 and 6.4 which occur more than 10^4 times are recommended as a conservative alternative.

(3) For the calculation of bending moments along the tower using second order theory, load-dependent stiffness reduction shall be applied.

5.5 Fibre Reinforced Plastics (FRP) and Bonded Joints

5.5.1 General

(1) The analyses are carried out with characteristic values which are determined from test results as described in Section 5.5.2.3. Verification shall be provided in such a way that the design values of the actions S_d are smaller than the design values of the component resistances R_d (characteristic value R_k divided by the partial safety factor for the material γ_{Mx}):

$$S_d \le R_k / \gamma_{Mx} = R_d$$

(2) If there are no test results or other confirmed data for the analysis, the minimum characteristic values given in Sections 5.5.4 to 5.5.6 may be used. By start of production at the latest, it shall be verified that the material attains at least the characteristic values assumed in the analysis.

5.5.2 Materials

5.5.2.1 Requirements for manufacturers

(1) The production of FRP components which were assessed by GL shall preferably take place at manufacturers approved by GL.

(2) The requirements for the manufacturers of rotor blades are set out in Section 3.1. Type and scope of the shop approval are also laid down there.

(3) The requirements for acknowledgement of a quality management system at the manufacturer, as well as the procedure for obtaining the acknowledgement and maintaining it, are given in Section 3.2.

(4) Special requirements as regards production are included in Sections 3.4.3 to 3.4.5.

5.5.2.2 Requirements for the materials

(1) Only materials with confirmed properties may be used. In some cases, GL approval is needed in addition; see Section 3.4.3.4, para 1, and Section 5.5.6, para 5.

(2) Requirements and quality verification (certificates, test reports, approvals) for the usual structural materials are listed in Sections 3.3.3.8 and 3.4.5.2, para 1.

(3) The strengths and stiffnesses of the materials used shall be sufficiently known in each case, i.e. modulus of elasticity (E-modulus), Poisson's number, failure strain and the failure stress of the typical laminate layers used, both for tensile and compressive loading parallel and transverse to the fibres and also for shear.

(4) The glass transition temperature (extrapolated onset temperature T_{eig} according to ISO 11357-2) of the matrix and of the structural bonding materials shall be higher than 65 °C and also higher than the temperature which is expected at the structural member.

5.5.2.3 Characteristic values

(1) The characteristic values R_k are generally calculated as follows:

$$R_k(\alpha, P, \upsilon, n) = \bar{x}\left[1 - \upsilon\left[U_\alpha + \frac{U_p}{\sqrt{n}}\right]\right]$$

where:

U_i = i% fractile (percentile) of the normal distribution

n = number of tests

$\bar{x}$ = the mean of the test values

υ = coefficient of variation for n test values

(2) For the equation, it is assumed that the standard deviation of the observed values corresponds to that of the normal distribution. The inaccuracies occurring thereby are covered by the reduction factors.

(3) The α = 5 % fractile for a probability P = 95 % (confidence level) assuming a normal distribution (DIN 55303, Part 1) shall be applied. This yields:

$$\mathrm{R_k}(5\%, 95\%, \upsilon, \mathrm{n}) = \bar{\mathrm{x}}\left[1 - \upsilon\left[1.645 + \frac{1.645}{\sqrt{\mathrm{n}}}\right]\right]$$

5.5.2.4 Partial safety factors for the material

(1) The partial safety factors for the material γ_{Mx} shall be determined separately for

- the short-term verification (x = a),

- the fatigue verification (x = b),
- the stability analysis (x = c), and
- the bonding analysis (x = d and x = e).

These factors are obtained by multiplying the partial safety factor γ_{M0} with the reduction factors C_{ix} :

$$\gamma_{Mx} = \gamma_{M0} \cdot \prod_i C_{ix}$$

For all analyses, the partial safety factor γ_{M0} is:

$$\gamma_{M0} = 1.35$$

The reduction factors C_{ix} listed below apply without further verification. Reduction factors verified by experiment may be used as an alternative.

(2) In the short-term strength verification, γ_{Ma} shall be determined by multiplication of γ_{M0} as per Section 5.5.2.4, para 1, with the reduction factors C_{ia} . To take account of influences on the material properties, the following reduction factors shall be used:

C_{1a} = 1.35 influence of ageing

C_{2a} = 1.1 temperature effect

C_{3a} = 1.1 laminate produced by prepregs, winding techniques, pultrusion or resin infusion method

= 1.2 wet laminate with hand lay-up, pressing techniques

C_{4a} = 1.0 post-cured laminate

= 1.1 non post-cured laminate

(3) In the fatigue verification, γ_{Mb} shall be determined by multiplying γ_{M0} (see Section 5.5.2.4, para 1) with the following reduction factors C_{ib} :

C_{1b} = $N^{1/m}$ curve of high-cycle fatigue for the load cycle number N and slope parameter m.
m is determined by an analysis (S/N curve) to be agreed with GL. Regarding simplified assumptions for m, see Sections 5.5.4, para 13, and 5.5.5, para 6.

C_{2b} = 1.1 temperature effect

C_{3b} = 1.0 unidirectional (UD) reinforcement products

= 1.1 non-woven fabrics and UD woven rovings

= 1.2 woven fabrics and mats

C_{4b} = 1.0 post-cured laminate

= 1.1 non post-cured laminate

C_{5b} = 1.0 to 1.2
local partial safety factor for the blade trailing edge. The exact magnitude depends on the quality of the verification (1.0 for dynamic blade test in the edgewise direction, 1.1 for FE calculation, 1.2 for calculation according to Bernoulli theory).

5.5.3 Analyses

5.5.3.1 General

(1) The design values for the strains or the stresses are determined by the requirement to prevent laminate failure and stability failure with regard to the short-term strength, fatigue strength and stability in all load cases. The discontinuities in the laminate, the load introduction zones and the high load cycle numbers shall be taken into account.

(2) The actual safety shall be documented in the analysis for short-term strength and fatigue strength by a failure hypothesis for anisotropic materials that is acknowledged in the literature, e.g. as per VDI 2014 or Puck [5.6]. The use of other failure hypotheses is possible after consultation with GL. For the strength analysis, a separate verification shall always be provided for fibre failure and inter-fibre failure.

If a failure hypothesis as mentioned above is used, the coefficients shall be included as follows:

$p_{\perp II}^{(-)} = 0.25$

$p_{\perp II}^{(+)} = 0.3$

where $p_{\perp II}^{(-)}$ and $p_{\perp II}^{(+)}$ are the inclination parameters according to Puck [5.6].

(3) The verifications for fibre failure and inter-fibre failure and for stability regarding short-term and fatigue strength can be provided in the form of strain or stress analyses.

5.5.3.2 Analysis for ultimate load

5.5.3.2.1 Analysis for fibre failure

(1) The analysis for fibre failure shall be carried out for areas under tensile, compressive and/or shear loading using the design values of the actions S_d .

5.5.3.2.2 Analysis for inter-fibre failure

(1) The inter fibre failure shall be verified by computational means as per Section 5.5.3.1, para 2, for each individual layer of laminate. To determine the permissible failure stresses and failure strains parallel and transverse to the fibres and for shear that are necessary for this verification, the mean of the tested strength values shall be divided by the product of the partial safety factor γ_{M0} and the following reduction factor C_{IFF}:

C_{IFF}	=	1.25	to account for changes of material properties due to temperature, ageing etc.

The analysis for inter-fibre failure shall be performed with the characteristic values of the actions.

Note:

The transverse strains can be determined by computation or by experiment.

As an alternative to verification for inter-fibre failure by computational means, one of the following methods of verification may be used:

(2) Verification based on a fatigue test of the rotor blade fulfilling the following requirements:

- previous inter-fibre failure analysis based on static test loads (see Section 6.2.5) for determining critical areas of the rotor blade structure
- conducting of static rotor blade tests according to Section 6.2.5
- conducting of fatigue tests with the same rotor blade according to IEC 61400-23
- subsequent inspection of the rotor blade by GL
- assessment of the test results by GL

(3) Fatigue analysis based on S/N curves: The S/N curves shall be established using an acknowledged abort criterion for inter-fibre failure (e.g. decrease in stiffness, increase of light scattering). A defined initial static load shall be applied to the test specimen. The geometry of the test specimen and the extent of the initial static load shall be agreed with GL in advance.

***Note*:**

For all fabrics used, the verification shall be carried out for all relevant load directions in the rotor blade. For operating temperatures below -30 °C, the tests shall be carried out at the lowest temperature to be expected during operation.

5.5.3.2.3 Stability analysis

(1) The stability (against buckling and wrinkling) of parts under tensile, compressive and/or shear loading shall be verified on the basis of the design values for the actions S_d. At any location, the least favourable combination of bending, compression and shear or a suitable conservative envelope shall be determined and used for the verification (refer also to Section 6.2.4.1, para 4).

(2) For the stability analysis, the partial safety factor for the material γ_{MD} shall be applied to the mean values of the material stiffnesses in order to determine the design values of the component resistances R_d. γ_{MD} shall be determined by multiplying the partial safety factor γ_{M0} (see Section 5.5.2.4, para 1) with the following reduction factors C_{ic}:

C_{1c}	=	1.1	to account for the scattering of the moduli
C_{2c}	=	1.1	temperature effect (see Sections 5.5.4, para 15, and 5.5.5, para 8)
C_{3c}	=	1.25	for linear computations

(3) Where verification is performed by analytical computation, the assumptions and estimates made shall be of realistic nature (e.g. the boundary conditions).

(4) For linear FE-computations, a sufficient accuracy of the mesh shall be demonstrated. A sufficient accuracy of the mesh may be assumed as soon as the buckling eigenvalue does not change by more than 5 % if the number of elements is doubled.

(5) The stability analysis may be performed by means of a (geometrically) non-linear FE computation with a minimum of 10 time steps. The load vectors shall thereby follow the deformation of the structure. For each loading, a stress-free predeformation affine to the 1st linear buckling eigenform shall be applied to the structure. The global scaling of the 1st linear eigenform shall be performed in such a way that the maximum height of the critical buckle is 1/400 of its largest horizontal dimension (wavelength). A smaller predeformation can be permitted if its height is verified. Under these circumstances, a fibre failure analysis for the entire rotor blade structure is required. The characteristic short-term strength considering the reduction factor C_{1a} according to Section 5.5.2.4, para 2, shall not be exceeded.

Note:

The partial safety factor γ_{MD} may be applied to the loads for simplification. The inaccuracy connected with this approach is assumed to be small.

(6) In the case of a stability analysis using a nonlinear FE computation, additional verification shall be provided according to a linear method, in order to determine the 1st bifurcation load. This load shall be larger than the characteristic load. In addition, it shall be shown that, as a result of the buckling after predeformation, no damage can occur at the adjacent structural members and structural details (e.g. at the bonded joints).

(7) As an alternative to the required stability analysis by means of an analytical approach, stability can be verified by testing. In this case, the design values for the loads and the reduction factors as per Section 5.5.3.2.3, para 2, shall be taken into account, whereby the reduction factor $C_{3c} = 1.0$ shall be applied. The reduction factor C_{1c} shall be kept at 1.1, unless tests on multiple test specimens are performed. If the tests are to be performed on structural components or samples, the conditions for the acknowledgement of these tests shall be defined beforehand in consultation with GL.

5.5.3.3 Fatigue analysis

(1) The fatigue analysis is based on the characteristic (see Section 5.5.2.3) S/N curve established for the laminate in question and the Goodman diagram constructed using this curve. If no S/N curve is available for the laminate, it shall be assumed to be as given in Section 5.5.2.4, para 3 (factor C_{1b}), and Sections 5.5.4, para 13, and 5.5.5, para 6.

(2) The Goodman diagram shows the relationship between the mean and the range components of the component resistances R and actions S (R and S as strains ε or stresses σ) and may be constructed as in Fig. 5.5.1.

The number of tolerable load cycles N may be determined as follows:

$$N = \left[\frac{R_{k,t} + \left|R_{k,c}\right| - \left|2 \cdot \gamma_{Ma} \cdot S_{k,M} - R_{k,t} + \left|R_{k,c}\right|\right|}{2 \cdot \left(\gamma_{Mb}/C_{1b}\right) \cdot S_{k,A}} \right]^m$$

where:

$S_{k,M}$ = mean value of the characteristic actions

$S_{k,A}$ = amplitude of the characteristic actions ($|S_{k,max} - S_{k,min}|/2$)

$R_{k,t}$ = characteristic short-term structural member resistance for tension

$R_{k,c}$ = characteristic short-term structural member resistance for compression

m = slope parameter m of the S/N curve

The auxiliary variable m is laid down through an analysis (S/N curve) to be agreed with GL. For simplified assumptions, see Sections 5.5.4, para 13 and 5.5.5, para 6.

N = permissible load cycle number

γ_{Ma} = partial safety factor for the material (as per Section 5.5.2.4, short-term strength)

γ_{Mb} = partial safety factor for the material (as per Section 5.5.2.4, fatigue strength)

C_{1b} = $N^{1/m}$, see Section 5.5.2.4, para 3 [i.e. (γ_{Mb}/C_{1b}) corresponds to γ_{Mb} without C_{1b}]

(3) For given actions, the Goodman diagram can be used to determine the permissible load cycle numbers N, which can be used to carry out a damage accumulation calculation. The damage D is defined as the sum of the quotients of existing load cycle numbers n_i to permissible load cycle numbers N_i. D must be less than unity:

$$D = \sum_i \frac{n_i}{N_i} \leq 1$$

where:

D = damage

n_i = existing number of load cycles of a class i of actions

N_i = permissible number of load cycles of a class i of actions

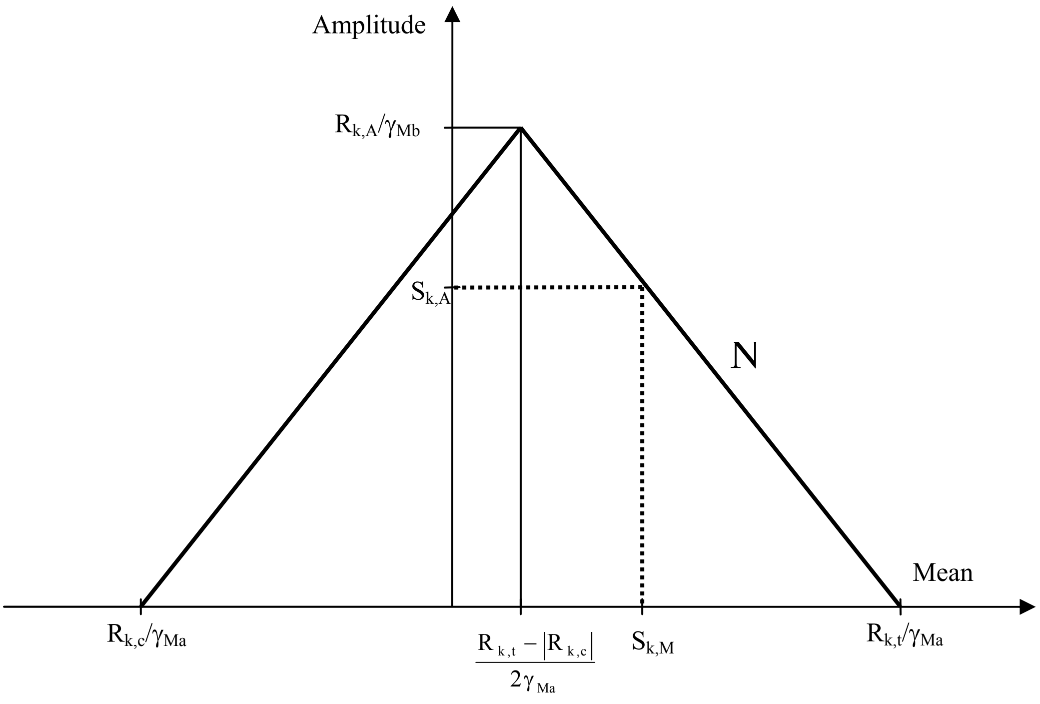


Fig. 5.5.1 Goodman diagram

$R_{k,A}$ = amplitude of the characteristic structural member resistances for load cycle number N = 1 (see Section 5.5.4, para 14, for glass fibre reinforced plastics and Section 5.5.5, para 7, for carbon fibre reinforced plastics)

5.5.4 Glass fibre reinforced plastics (GRP)

(1) To determine the strength and the stiffness of materials used for structural members at allowable ambient temperatures between -30 °C and +50 °C, at least the tests below shall be performed by a laboratory acknowledged by GL or by an accredited laboratory.

(2) The test results, after being statistically processed to gain characteristic values (refer to Section 5.5.2.3, para 1), may be used as guidance values for the nominal values chosen for the strength verification.

(3) It shall be proven that the materials used in production do attain characteristic strength values (see Section 5.5.2.3) above the nominal values for strength verification. Other material values (i.e. moduli) assumed within calculation/verification may not fall below the values specified in the design documentation, and may not exceed those values by more than 10 %.

(4) Regarding the stiffness/mass distribution, the design values shall be adequately represented for the purpose of load and natural frequency calculation.

(5) Tests for matrix and bonding material:

- determination of temperature of deflection under load (according to ISO 75-2, with at least 3 specimens); minimum temperature for the glass transition temperature according to Section 5.5.2.2, para 4

(6) Tests for composite:

- determination of representative fibre, resin and void volume fraction (ISO 1172) for all samples used in the following tests. Regarding the maximum allowable fibre volume fraction, see Section 5.5.4, para 13 (Section 5.5.5, para 6 for carbon fibre reinforced plastics).

Tests dominated by fibre failure:

The test results have to be recalculated according to the different fibre volume fractions found in test specimens and in production laminate. The fibre volume content of the test specimens shall not deviate by more than ±5 percent points [%] from the fibre volume content found in production laminates.

- tension test parallel to the fibre direction (ISO 527-4 /-5, Type A) at normal climate 23/50 as defined in ISO 291 with a minimum of 6 specimens to determine tensile strength, failure strain, E-modulus and Poisson's number

- compression test parallel to the fibre direction (ISO 14126) at normal climate 23/50 as defined in ISO 291, test piece form B with a minimum of 6 specimens to determine compressive strength, failure strain and E-modulus

Tests dominated by inter-fibre failure:

A recalculation of the test results according to the different fibre volume fractions found in test specimens and in production is not allowed.

However, the test values can be directly taken for calculation if the difference in fibre volume fraction between test specimen and production laminate does not exceed ±2,5 percent points [%].

For tension and compression tests perpendicular to the fibre direction, the maximum fibre weight parallel to the load direction is not allowed to exceed 5%.

- tension test perpendicular to the fibre direction (ISO 527-5, Type B) at normal climate 23/50 as defined in ISO 291 with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus
- tension test for ± 45° laminates (ISO 14129) at normal climate 23/50 as defined in ISO 291 with a minimum of 6 specimens to determine the shear strength
- compression test perpendicular to the fibre direction (ISO 14126, Type B) at normal climate 23/50 as defined in ISO 291 with a minimum of 6 specimens to determine compressive strength and failure strain

(7) Tests on sandwich structures:

- shear test following the lines of DIN 53294 (or ASTM C 273) for the core and the face layers of a design-typical sandwich laminate at normal climate 23/50 as defined in ISO 291 with a minimum of 6 specimens to determine the shear modulus and the shear strength. The test procedure and production of the specimens shall be agreed with GL in advance.

(8) For allowable ambient temperatures lower than -30 °C, at least the following tests shall be performed additionally:

(9) Tests for matrix and bonding material:

- determination of the dynamic mechanical properties (DIN EN ISO 6721-5) for the matrix and the bonding material with a starting temperature which is 10 °C beneath the lowest allowable ambient temperature; 3 specimens
- lap-shear test following the lines of DIN EN 1465 or equivalent tests for layers of a design-typical adhesively bonded laminate at room temperature and at the lowest allowable ambient temperature; 6 specimens each. The test procedure and production of the specimens shall be agreed with GL in advance.

(10) Tests for composite:

- tension test perpendicular to the fibre direction (DIN EN ISO 527-5, Type B) with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus for the lowest allowable ambient temperature
- tension test for ± 45° laminates (DIN EN ISO 14129) with a minimum of 6 specimens to determine the shear stress and the shear modulus for the lowest allowable ambient temperature

(11) Tests on sandwich structures:

- shear test following the lines of DIN 53294 (or ASTM C 273) for the core and the face layers of a design-typical sandwich laminate at the lowest allowable ambient temperature with a minimum of 6 specimens to determine the shear modulus and the shear strength. The test procedure and production of the specimens shall be agreed with GL in advance.

(12) Other quantities which may be needed can be derived from the test values or taken from the literature. Other standards can be chosen after prior consultation with GL. The test results shall as a rule be verified every 4 years.

(13) The slope parameter m in factor C_{1b} for the fatigue verification as per Section 5.5.2.4, para 3, may be assumed as follows with consideration of Section 3.3.3.4, para 4:

- $m = 9$ for laminates with polyester resin matrix
- $m = 10$ for laminates with epoxy resin matrix

This value of m applies for laminates with a fibre content of at least 30 % and at most 55 % by volume without further verification. For other fibre volume contents and matrix resins, an appropriate analysis (S/N curve) shall be performed.

(14) The amplitude of the characteristic structural member resistances for load cycle number N=1 may be assumed as

$$R_{k,A} = (R_{k,t} + |R_{k,c}|)/2$$

For fibres with a ± 45° orientation to the main load axis $R_{k,A}$ may be assumed as

$$R_{k,A} = 1.85\% \text{ (as strain)}$$

(15) The factor C_{2x} applies for the influence of ambient temperatures between –30 °C and 50 °C, if the drop in the shear or flexural moduli of the laminates at 50 °C compared with that at 23 °C is not greater than 20 %.

(16) Structures whose load-bearing laminate is built up from unidirectional glass-fibre reinforcement layers may be qualified with regard to short-term and fatigue strength by a simplified strain verification. At design values of the actions, the strain along the fibre direction shall remain below the following design values:

- tensile strain $\varepsilon_{Rd,t} \leq 0.35\%$
- compressive strain $\varepsilon_{Rd,c} \leq |-0.25|\%$

(17) The design value for the mean bearing stress of load introduction zones shall not exceed 100 N/mm² in the fibre direction without further verification. The content of unidirectional fibres in force direction has to be at least 35 %.

5.5.5 Carbon fibre reinforced plastics (CRP)

(1) The characteristic values prescribed in this section refer to high-tensile (HT) reinforcement fibres. For the verification of other fibre types (HM, HS, IM, pitch-based fibres, “heavy tows” etc.) the analysis shall be agreed with GL (see Section 3.3.3.4, para 5).

(2) In the case of direct contact between CRP and metallic components, possible damage from contact corrosion shall be excluded by suitable measures.

(3) The mechanical properties on compression parallel to the fibre direction shall be proved by tests. The laminate quality of the test specimens shall be equivalent to that of the later production line. The quality of laminate (direction and waviness of fibres, porosity etc.) shall be specified in the production specification for the component.

(4) For the determination of the strength and stiffness of materials used for allowable ambient temperatures between -30 °C and +50 °C, refer to Section 5.5.4, para 5 to para 7. In deviation from this, two tests shall be made according to the following standards for allowable ambient temperatures between -30 °C and +50 °C:

- tension test perpendicular to the fibre direction (DIN EN 2597) with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus
- compression test parallel to the fibre direction (DIN EN 2850, draft of April 1998), test piece form A1 (reduction of the free buckling length to 8 mm ± 0.25 mm is allowed) with a minimum of 6 specimens to determine compressive strength, failure strain and E-modulus.

(5) For allowable ambient temperatures lower than -30 °C, Section 5.5.4, para 8 to para 11 shall apply. In deviation from this, a test shall be made according to the following standards in the case of allowable ambient temperatures lower than -30 °C:

- tension test perpendicular to the fibre direction (DIN EN 2597) with a minimum of 6 specimens to determine tensile strength, failure strain and E-modulus

(6) The slope parameter m in factor C_{1b} for the fatigue verification as per Section 5.5.2.4, para 3, may be assumed as m = 14 for CRP. This applies without further verification for laminates with a fibre content of at least 50 % and at most 60 % by volume and an epoxy resin matrix. For other fibre volume contents and matrix resins, an appropriate analysis (S/N curve) shall be performed.

(7) The amplitude of the characteristic structural member resistances for load cycle number N=1 may be assumed as

$$R_{k,A} = (R_{k,t}+|R_{k,c}|)/2$$

For fibres with a ±45° orientation to the main load axis $R_{k,A}$ may be assumed as

$R_{k,A} = 1.1\%$ (as strain)

(8) The factor C_{2x} applies for the influence of ambient temperatures between -30 °C and 50 °C, if the drop in the shear or flexural moduli of the laminates at 50 °C compared with that at 23 °C is no more than 20 %.

(9) Structures whose load-bearing laminate is built up from unidirectional carbon-fibre reinforcement layers may be qualified with regard to short-term and fatigue strength by a simplified strain verification, provided a high laminate quality can be verified. At design values of the actions, the strain along the fibre direction shall remain below the following design values for the strains:

- tensile strain $\varepsilon_{Rd,t} \leq 0.24\%$
- compressive strain $\varepsilon_{Rd,c} \leq |-0.18|\%$

(10) The mean bearing stress of load introduction zones shall not exceed the value of 150 N/mm² in the fibre direction without further verification.

5.5.6 Bonded joints

(1) The strength analysis for bonding shall be performed according to Section 5.5.3, with the necessary changes. Stress concentrations within the bonding surfaces and flaws shall be taken into account (see Section 3.4.4.1, para 2).

(2) The application limits for the adhesive prescribed by the manufacturer shall be observed. Bonded joints shall be so designed that peeling moments or forces are avoided to the greatest possible extent.

(3) If the analyses are based on characteristic values obtained in tests, it shall in each case be checked that the findings concerning stress concentrations in the specimen can be transferred to the actual structural members. If necessary, the characteristic values shall be corrected in proportion to the various stress concentrations.

(4) To determine the allowable shear stress for steady stress curves, lap-shear tests or equivalent tests shall be performed at 23 °C and 50 °C for the adhesive used. The test procedure and production of the specimens shall be agreed with GL in advance. The partial safety factor for the material γ_{Md} shall be applied to the characteristic value that is determined. γ_{Md} shall be obtained by multiplying the partial safety factor γ_{M0} (see Section 5.5.2.4, para 1) by the following reduction factors C_{id}:

C_{1d}	=	1.5	influence of ageing
C_{2d}	=	1.0	temperature effect
C_{3d}	=	1.1	bonding surface reproducibility
C_{4d}	=	1.0	post-cured bond
	=	1.1	non post-cured bond

(5) For the static strength verification, a characteristic shear stress of

$$\tau_{Rk} = 7\ \text{N/mm}^2$$

can be used without further verification, in the case of multi-component thermosetting adhesives approved by GL. A stress concentration arising in the structural member is covered by this value up to a factor of 3. This value may be assumed for bonded joints of shell and web.

(6) For the fatigue strength verification, a calculation on basis of a Goodman diagram and an S/N curve shall be performed. The characteristic S/N curve shall be determined from tests at normal climate 23/50 as defined in ISO 291. Shear fatigue tests imaging the real shear connections with at least 4 different load levels and at least 3 test specimens per load level are required. The lowest load level chosen shall lead to an amount of at least 10^7 load cycles (suggested amounts of load cycles are: N=1, N=10^4, N=10^6, N=10^7). The R-relation shall be 0.1. The test procedure and production of the specimens shall be agreed with GL prior to the tests.

***Note*:**

Values of geometric dimensions of the bonded joints (e.g. width or thickness) having an influence on the calculation shall consider the most disadvantageous manufacturing tolerance.

(7) The partial safety factor for the material γ_{Me} shall be applied to the characteristic S/N curve that is determined. γ_{Me} shall be determined by multiplying the partial safety factor γ_{M0} (see Section 5.5.2.4, para 1) with the following reduction factors C_{ie} :

C_{1e}	=	1.0 for single lap-shear tests	
	=	1.1 for double lap-shear tests	
C_{2e}	=	1.1	temperature effect
C_{3e}	=	1.1	bonding surface reproducibility
C_{4e}	=	1.0	post-cured bond
	=	1.1	non post-cured bond

In the fatigue verification, the influence of the mean stress shall be taken into account analogously to Section 5.5.3.3, para 2 and para 3.

(8) As an alternative to fatigue strength verification procedure outlined under Section 5.5.6, para 6 and 7, the following simplified procedure may be performed:

The fatigue verification for joints that feature a steady shear stress curve without discontinuities (e.g. connection between web and shell or upper and lower shells for rotor blades) is provided for multi-component thermosetting adhesives approved by GL, if the stress range from the equivalent constant-range spectrum (mean values remain unconsidered) for 10^7 load cycles and a variation of the Wöhler exponent from m=4 to m=14 is less than

$$\tau_{Rd} = 1.0\ \text{N/mm}^2$$

The procedure may be applied for the verification of bonded joints of shell and web.

(9) For bonded joints connecting pre-fabricated blade root laminate and pre-fabricated spar cap elements, additionally to the computational verification, tests shall be performed with the loads derived from the computational verification. The test loads shall be determined according to the simplified computational procedure as described in Section 5.5.6 , para 8, and multiplied by the safety factors according to Section 5.5.6, para 7.

(10) Successful tests on at least 3 samples (being representative for the jointed components in geometry and material) shall be performed with a minimum number of load cycles of $N=10^6$. The testing procedure and the samples shall be agreed with GL prior to the tests.

(11) For the fatigue verification of load introduction points (e.g. metallic inserts) a characteristic S/N curve shall be determined from tests at normal climate 23/50 as defined in ISO 291. The influence of moisture on the joint shall be taken into account.

Appendix 5.A Strength Analyses with the Finite Element Method

5.A.1 General

Requirements and recommendations regarding the definition of objective, type and scope of a strength analysis as well as calculation and details on evaluation and documentation are given in the following. The necessary scope depends on the particular project in each case and can deviate from the requirements described here.

5.A.1.1 Introduction

(1) The goal of this appendix is to provide information and instructions on the strength analyses of the wind turbine with the finite element method (FEM), on the basis of the requirements specified in the Guideline. Here the aim is to prevent errors in selecting the method, in the modelling and performing of the analysis and in the interpretation of the results, and to permit an assessment of the results that is both independent of the person and program in question and leads to useful structural conclusions. The appendix serves as an application-related supplement to the general guidelines and recommendations which contribute towards the quality assurance of finite element analyses. In this connection, reference is made to the more detailed specialist literature, which includes the publications of NAFEMS (International Association for the Engineering Analysis Community). The following refers primarily to metallic structures. For structures made of fibre reinforced plastics, the statements shall apply with the necessary adaptions.

(2) In general, strength analysis consists of the following steps, which are described in more detail in the sections below:

- modelling of the structure and the boundary conditions
- determination and modelling of the primary loads and load cases
- execution of the analysis
- verification of the model
- evaluation and assessment of the results

In conclusion, the procedure shall be documented (see Section 5.A.5).

(3) In modelling the structure as well as the boundary conditions and loading, certain simplifications are possible or even necessary, depending on the objective of the analysis and the type of structure. Since these aspects are determined by the possibilities offered by the available programs and computers, as well as by the envisaged extent of analysis, and can also change with the increasing state of knowledge, the following explanations are necessarily expressed in a generalized form, in order that they can remain applicable to a large number of cases. In addition to a short presentation of procedures currently in use, several notes are given on what should be observed during the modelling, analysis and assessment, especially for the various structures and components of wind turbines. Further instructions and information can be obtained from the more detailed specialist literature and from the descriptions of the software.

(4) The type and extent of the analysis depends primarily on the kind of structural response to be assessed. As a rule, the following structural responses are foremost in strength analyses:

- stresses and deformations for specified load conditions
- failure behaviour and magnitude of the failure limit loading (e.g. buckling load)
- eigenfrequencies and eigenmodes for determining critical structural responses

The structural response is either assessed directly or in subsequent calculations.

(5) External loads as per Chapter 4 and possibly additional forces from the dead weight and accelerated masses shall be taken into account as the loading. In the case of time-variant loading, the dynamic behaviour of the structure shall, if applicable, be considered in the form of dynamically increased loads and/or structural responses (e.g. tower or drive train) or, as an alternative, dynamic analyses shall be performed (however, these are not discussed further here).

(6) It shall be noted that the structural response can depend on the loading magnitude in a linear or a non-linear manner. Non-linear effects can be of significance in the following cases:

- generally for an analysis of the failure behaviour of the structure

- geometric non-linearity: for relatively flexible structures with large deformations
- structural non-linearity: for contact problems or variable boundary conditions, e.g. load-dependent opening of bolted connections
- material non-linearity: non-linear material behaviour through plastification of structural regions

(7) In the structural design of wind turbines, the deformations and stresses can usually be subdivided into the following categories, depending on the structural conditions:

- global deformations and stresses of the primary structural components (hub, main frame, tower etc.)
- local deformations and stresses of the primary structural components and their structural details (e.g. stiffeners)
- locally increased stresses at structural details

The objective of the strength analysis and the kind of modelling, loading and evaluation can refer to one of these categories, which are described in more detail in Sections 5.A.1.3 to 5.A.1.5.

5.A.1.2 Determining the objective, type and extent of the strength analysis

(1) The objective, type and extent of the strength analysis must be laid down clearly, since these aspects have a decisive effect on the modelling of the structure and the loading.

(2) The objective of the analysis results from the alternatives described in Section 5.A.1.1, para 4, whereby the category of the deformations and stresses to be considered in the analysis must be determined; see also Section 5.A.1.1, para 7, and Sections 5.A.1.3 to 5.A.1.5.

(3) The type of analysis comprises either a linear or a geometric-, structural- and/or material-related non-linear analysis; see Section 5.A.1.1, para 6.

(4) The extent of analysis is mainly oriented towards the selected extent of the model and the necessary mesh fineness; see also Sections 5.A.2.1 to 5.A.2.3.

5.A.1.3 Global deformations and stresses

(1) The structural response under tensile, shear, bending and torsional load consists of global (i.e. large-area) deformations and stresses. Particularly for complex geometries (e.g. main frame) or loads (e.g. hub), the structural responses to be expected cannot be modelled by the laws of the beam or plate theory.

(2) The resulting stresses are nominal stresses, i.e. stresses which would result from integral quantities of the section loads and cross-section values. Global nominal stresses contain no local stress increases; these must be superposed additionally (see Sections 5.A.1.4 and 5.A.1.5).

5.A.1.4 Local deformations and stresses

(1) Additional local deformations and stresses can occur due to the structural details of components (e.g. stiffeners, webs, flange plates and cut-outs, radii and transitions).

(2) The structural details of components include stiffeners, webs, flange plates and cut-outs, radii and transitions.

(3) The resulting local stresses are also nominal stresses (see Section 5.A.1.3, para 2) which have superposed themselves on the global stresses. This superposition can arise through eccentricities or other re-directionings in the force path which generate additional moments or forces locally. In addition, locally increased stresses can arise at structural details.

5.A.1.5 Locally increased stresses

(1) At structural details and discontinuities, locally increased stresses which must be assessed especially in respect of fatigue strength can occur. Here a distinction is made between two types of stresses:

- the maximum stress in the notch root; see para 2
- the structural hot-spot stress defined specially for welded joints; see para 3

(2) The maximum stress at notched components can exceed the elastic limit of the material. Instead of the non-linear notch stress σ and strain ε, the notch stress σ_k can be determined and assessed for normal cases under the assumption of linear-elastic material behaviour. In the case of notches, the local supporting effect of the (ductile and semi-ductile) material can be considered.

(3) In complex welded structures, only the stress increase as a result of the structural geometry is generally calculated in the FE analysis, whilst that caused by the weld itself is (only) considered during the assessment by the adequate detail category (see Section 5.3.3.5.1). This leads to the structural hot-spot stress σ_S at the weld toe. It is determined under the assumption of elastic material behaviour.

(4) Apart from a direct calculation of the locally increased stresses, it is possible to use catalogued stress concentration factors or detail categories. When using concentration factors and detail categories, the associated nominal stresses must be determined with sufficient accuracy in accordance with their definition. Moreover, the ranges of application and validity for the catalogued data shall be observed.

(5) Further notes on the definition and determination of locally increased stresses are given in the fatigue strength analyses in Chapter 5.

5.A.2 Modelling of the structure

5.A.2.1 Extent of the model

(1) FE models for wind turbines are usually produced for the individual components. For these models, it shall be ensured that meaningful boundary conditions are introduced, in order to represent the interaction with the neighbouring structural areas in a suitable way. If necessary, adjacent components shall also be considered in the model (see Fig. 5.A.1). Non-linear effects shall be taken into account or linearized by means of suitable simplifications wherever applicable. If there is any risk that the results can be impaired by idealized boundary conditions, a correspondingly enlarged distance should be provided between the model boundary and the structural area under consideration.

(2) Partial models or submodels are used for local strength analyses of parts of the wind turbine components (see Fig. 5.A.2). Like 3D global models, partial models or submodels are generally used to analyse the complex, three-dimensional strength behaviour.

(3) Local models are used for the strength analysis of secondary or special components as well as structural details. The main focus of the investigations is usually on the analysis of the local structural behaviour and/or the locally increased stresses at structural details and discontinuities (detail from Fig. 5.A.3 or Fig. 5.A.4), which can be included in a coarse model (Fig. 5.A.3) but have no or only a minor influence on the current objective of the strength analysis (cf. Section 5.A.1.1, para 3). For this reason, the meshing of the half-model in Fig. 5.A.3 has been selected appropriately for the task at hand (sensitivity study), whereas it is not suitable for quantitative stress analyses of the supporting bracket.

Example:

The objective of the analysis for the supporting bracket in Fig. 5.A.4 (application of the submodel technique with the aim of analysing the influence of the weld seam of the supporting brackets with respect to the fatigue behaviour of the entire structure) differs fundamentally from the objective of analysis using the half-model (sensitivity study on the arrangement of the tower shell at the tower top flange / detail 1 in Fig. 5.A.3).

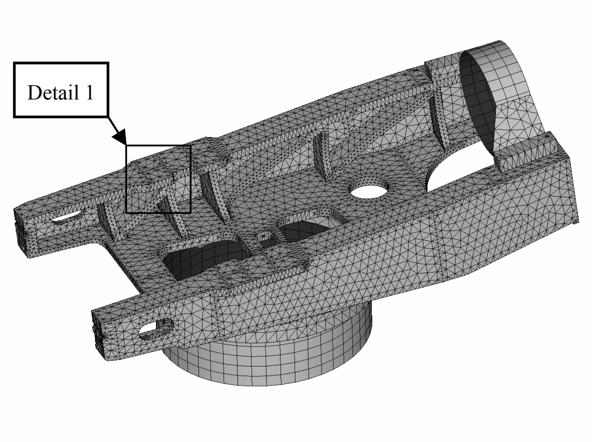


Fig. 5.A.1 **Model of a main frame with adjacent components**

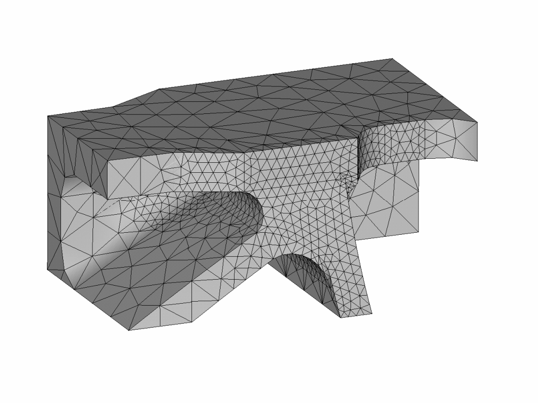


Fig. 5.A.2 **Submodel of the main frame (detail 1 from Fig. 5.A.1)**

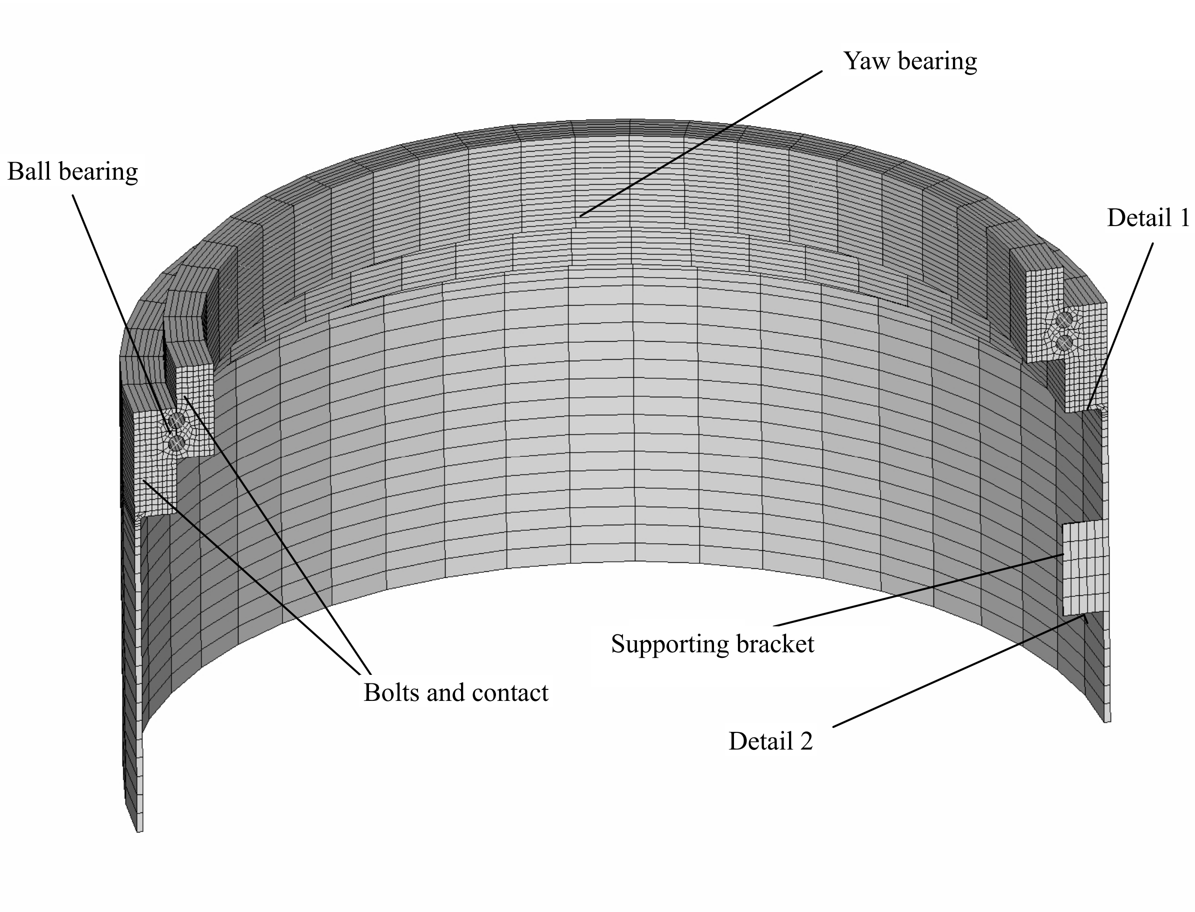


Fig. 5.A.3 **Half-model for a sensitivity study on the arrangement of the yaw bearing at the tower top**

5.A.2.2 Selecting the elements

(1) Selecting the type of element to be used primarily depends on the objective of the analysis. The characteristics of the selected element type must be able to reflect with sufficient accuracy the stiffness of the structure and the stresses to be analysed. When carrying out a strength analysis, adequate knowledge of the characteristics of the elements used is a basic requirement; the program documentation and applicable literature should be consulted.

(2) Usually, the following types of elements are used for strength calculations of wind turbine structures:

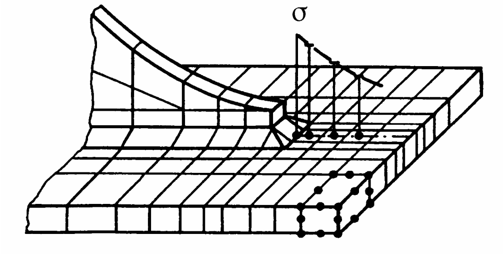


Fig. 5.A.4 **Local model (detail 2 from Fig. 5.A.3)**

- truss elements (1D elements with axial stiffness, but without bending stiffness)
- beam elements (1D elements with axial, shear, bending and torsional stiffness)
- plate and shell elements (2D elements with membrane, bending and torsional stiffness)
- solid elements (3D elements)
- boundary and spring elements
- contact elements (spring elements with non-linear spring characteristic)
- multipoint constraint elements

When using different element types, attention should be paid to the compatibility of the displacement functions as well as the transferability of the boundary loads and stresses, particularly for the coupling of elements with and without bending stiffness at the nodes.

(3) The selected element types must reflect the deformations and stresses for the load cases or the eigenmodes to be analysed, or reflect the failure behaviour when determining the magnitude of the failure limit loading. In some cases, certain effects of secondary importance can be excluded by suitable selection of the elements. A number of notes on the element types commonly used in the modelling of wind turbine structures are given below.

(4) In general, it must be determined how and to what extent the bending of components must be considered in the strength analysis. In cases of pure bending behaviour, the principles of the beam or shell theory can be applied with the corresponding element types. When using a solid element, a higher-order displacement function (e.g. with additional mid-side nodes) or a finer mesh may have to be chosen, if a corresponding bending behaviour is to be permitted.

(5) In local models, all stiffness components are generally of significance – even those of structural details – so that here plate, shell or solid elements are suitable. Further information on selecting elements in the calculation of locally increased stresses is given in Chapter 5 "Strength Analyses".

(6) With a view to evaluating the results, the arrangement of shell elements at the model surface may be useful for indicating the surface stress, since here the stress condition is biaxial. Here it shall be observed that the shell elements may not be allowed to exert any influence on the local stiffness.

5.A.2.3 Element subdivision

(1) The mesh fineness shall be chosen by considering the element characteristics in such a way that the stiffness conditions of the structure, the types of stresses to be analysed, and possibly also the failure behaviour are modelled with sufficient accuracy. The selection of the element type and the mesh fineness exert a particularly great influence on the calculation of locally increased stresses and also of the failure limit loading. Insufficiently fine mesh subdivision frequently leads to a considerable underestimation of the local stress peaks and overestimation of the failure limit loading. A few notes on the mesh subdivision normally used in modelling wind turbine structures are given below.

(2) In subdividing the mesh, the structural geometry and the positions of load introductions or supports shall be taken into account.

(3) Whilst observing the element characteristics, the element proportions shall be selected so that the stiffnesses and the resulting deformations and stresses are not falsified. For simple displacement functions, the ratio of the edge lengths of the element should be not greater than 3 : 1.

(4) In calculating locally increased stresses, the mesh fineness shall be increased gradually in accordance with the stress gradient. Further notes on mesh fineness in the calculation of locally increased stresses are given in the relevant literature (e.g. NAFEMS).

5.A.2.4 Simplifications

(1) Owing to the complexity of the wind turbine structure, simplifications are generally necessary in modelling, especially for global strength analyses. Simplifications are permissible, provided that the results are only impaired to a negligible extent.

(2) Small secondary components or details that only affect the stiffness of the global model to a lesser extent can be neglected in the modelling. Examples of this are small cut-outs, drill-holes and radii; their local stress increasing effects shall, however, be considered in a suitable manner (e.g. through application of stress concentration factors).

(3) Large cut-outs influence the global structure and always exert an effect in the local structure, and shall therefore be considered in all cases.

(4) Steps in the plate thickness or profile dimensions should lie on the element boundaries as far as possible. Insofar as they do not lie on the element boundaries, they shall be taken into account through correspondingly adapted element data or characteristics to obtain an equivalent stiffness.

(5) Plane elements should generally be positioned in the mid-plane of the corresponding components.

5.A.2.5 Boundary conditions and supports

(1) The provision of supports for the model by suppressing or prescribing of displacements or rotations serves several purposes:

- to suppress rigid body displacements and rotations of the model
- to model physically existent supporting points
- to model the interaction with the adjacent structural regions at the model edges

It shall be ensured that the supports do not cause any unrealistic constraints of the displacements or rotations.

(2) Physically existent supports that take up forces and moments should be modelled as realistically as possible with the actual supporting length and spring stiffness.

(3) For the strength analysis of the parts of the structures and components of wind turbines, the interaction with neighbouring structural regions at the model edges should also be modelled as realistically as possible. This can be done at planes of symmetry by means of symmetry or asymmetry conditions, insofar as the load and/or the structure is distributed symmetrically or asymmetrically. In certain cases, the interaction can also be portrayed by prescribed stresses, or forces and moments, at the boundary. These parameters can be obtained, for example, from the structural analyses of larger regions (submodel technique) or from beam forces and moments (e.g. tower segment). Non-linear boundary conditions shall be taken into account, and if applicable can be linearized (e.g. opening in flange joints, load transfer for roller and sliding bearing only via compressive loads).

5.A.2.6 Checking the input data

(1) The input data used for modelling the structural geometry and for the material characteristics shall be checked thoroughly for errors. The effectiveness of the data check can be increased appreciably by visualization of the data.

(2) The geometry of the finite element mesh should generally be reviewed by visual inspection. Here the possibility that individual elements have been entered twice by mistake, or that adjacent elements are not connected with each other, should also be taken into account. Furthermore, geometry data which are not immediately visible, such as the thickness of 2D elements or the cross-sectional properties of 1D elements, should also be checked.

(3) In addition to the geometry data, the material data as well as the boundary conditions and supports that were introduced should be checked carefully. Note that these parameters generally exert a considerable influence on the results.

(4) The checks performed shall be documented.

(5) Further notes on the extent, the requirements and the documentation are given in Section 5.A.5.

5.A.3 Loading of the structure

5.A.3.1 General

The relevant loads for the strength analyses of structures and components of a wind turbine shall be applied in accordance with Section 5.2.1 “General notes on the loading of the structure”.

5.A.3.2 Modelling the loads

(1) The loads shall be modelled realistically. If necessary, the modelling of the structure must be adapted to the modelling of the loads; see Section 5.A.2.3, para 2.

(2) Distributed loads (e.g. line or area loads) shall be converted – if applicable – to the equivalent node forces and moments, considering the displacement function of the elements.

(3) If the boundary deformations derived from coarse models of large structural areas are applied to local models, the correspondingly interpolated values shall be specified for the intermediate nodes.

5.A.3.3 Checking the load input

(1) The input data for the loads shall be checked thoroughly for errors. As is the case for the structural geometry, here too the effectiveness of the check can be increased considerably with the aid of suitable checking programs and visualization of the data.

(2) It is particularly important to check the sums of the forces and moments. For balanced load cases, it must be ensured that the residual forces and moments are negligible and that the reaction forces and moments correspond to the applied loads.

(3) The checks performed shall be documented. Further notes on the extent, the requirements and the documentation are given in Section 5.A.5.

5.A.4 Calculation and evaluation of the results

5.A.4.1 Plausibility of the results

(1) During the evaluation, the results shall be checked for plausibility. This involves in particular the visual presentation and checking of the deformations to see whether their magnitudes lie within the expected range and whether their distributions are meaningful with respect to the loads and boundary conditions or supports.

(2) Furthermore, it shall be checked whether the forces and moments at the supports lie within the expected order of magnitude.

(3) For local models with specified boundary deformations from the models of large structural regions, it is necessary to check whether the stresses near the boundaries correspond for the two models (verification of the submodel).

(4) Stress peaks shall be checked for plausibility of their location, distribution and magnitude of the stresses with regard to the loads and boundary conditions. Insofar as it is possible to define nominal stresses, concentration factors can be determined from the stress distribution and compared with tabulated concentration factors.

(5) For non-linear computations, it is necessary to check whether the solution was determined with sufficient accuracy in the non-linear zone.

5.A.4.2 Deformations

The deformations of the structure should generally be plotted so that other persons can perform a plausibility check of the results.

5.A.4.3 Stresses

(1) In strength analyses for specified load conditions (e.g. ultimate loads), the stresses of the entire component shall generally be represented pictorially. An exception is the analysis of locally increased stresses, for which it is possible that only the maximum value may be relevant.

(2) The stresses shall be checked with respect to the permissible values, as defined in Chapter 5. The corresponding stress category must be observed; cf. Section 5.A.1.1, para 7.

(3) For the stress evaluation, the changes in stress between the element centre and the element edge or corner must be taken into account. Simplifications in the model in relation to the real structure shall be included in the assessment. If cut-outs are considered in models with a coarse mesh in a simplified manner, the stresses shall be referred to the residual cross-section next to the cut-out.

(4) In models with relatively coarse meshes, local stress increases at existing structural details and discontinuities shall be included in the assessment, if their effect is not considered separately.

(5) To improve the clarity, it is recommended that the assessment be carried out with the aid of reserve factors which are obtained from the relationship between the permissible and the existing stress. In the case of extensive models, result tables should be set up.

(6) For analyses that are non-linear with respect to materials, the local strain shall generally also be determined and assessed in addition to the local elastic-plastic stress.

(7) For the fatigue verification of bolted connections in accordance with Section 6.5.2 by means of FEM, the maximum surface stress resulting from the tensile and bending stresses shall be considered.

5.A.4.4 Fatigue strength

(1) Fatigue strength aspects should generally be taken into account in the assessment of wind turbine components, owing to the cyclic stresses that are usually present.

(2) In the assessment of the stresses with regard to fatigue strength, the stress type shall be considered, i.e. whether nominal stresses or locally increased notch or structural stresses are calculated with the chosen model; see also Section 5.A.1.1, para 7.

(3) For the assessment, it is recommended that utilization ratios or reserve factors be calculated.

(4) Further notes, particularly on fatigue analyses, are given in Chapter 5.

5.A.4.5 Presentation of the results

(1) The results obtained and the conclusions made on the basis of these results shall be documented completely and clearly.

(2) The documentation can take the form of graphics and lists. In particular, lists are necessary when the graphic form is not suited to represent the results with sufficient accuracy. Extensive lists should be sorted, for example according to utilization ratio or reserve factors.

(3) All symbols and designations that are used should be explained, if possible in or before the plots and lists.

(4) Further notes on the extent, the requirements and the documentation are given in Section 5.A.5.4.

5.A.5 Documentation of FE analyses for the certification of wind turbines

5.A.5.1 General

The formal and content-related requirements for the documentation of computational analyses for the certification of wind turbine structures are set out in the following. The necessary scope may deviate from that described here.

5.A.5.2 General requirements for the documentation

(1) In this section, the requirements for the documentation are to a large extent presented independently of the analysis approach (analytical or FEM). They are oriented towards [5.7].

(2) From the technical and calculation viewpoint, the documentation of the computational analyses shall form a unified whole together with all other documents (drawings, specifications).

(3) The document shall have an unambiguous title designation with reference and revision number. The creation and release date shall be easily recognizable without doubt.

(4) The documentation shall be preceded by an overall table of contents reflecting the current state of revision in each case.

(5) The following shall be indicated:

- definition of the objective, type (methods used and theories applied) as well as extent of the calculation
- overall result, with statement of the primary load cases and indication of the utilization ratio and/or reserve factors that may be of special use for future margin studies based on these results (cf. also Section 5.3.3.2.2)

(6) the terms, symbols and units shall be described and applied clearly in the documentation.

(7) The selected ordering systems shall be presented clearly. If several ordering systems are used, then the ordering systems shall be allocated unambiguously to each other. The ordering systems include:

- coordinate systems
- sign conventions (e.g. for section or displacement quantities, or for stresses and strains)
- allocations (e.g. item numbers, components, node-element numbering)
- load cases and combination of load cases, subsystems of an overall system

The allocation of the data used in the ordering systems (e.g. entries and results) shall be clearly recognizable.

(8) Citations of standards and guidelines applied and of references (also of special analysis methods or models) reflecting the state of the art shall be named and listed according to their order of appearance in the documentation.

(9) The reference of the certified loads is made through statement of the load documentation with naming of the title, reference number and revision number. The partial safety factors used for the loads shall be documented. Insofar as time series are applied in the fatigue analyses, the lifetime-weighted load spectra for each load component shall be documented, in order to show without doubt that the valid and approved loads were used. Additionally, equivalent constant range spectra (damage equivalent loads) shall be documented.

(10) If mechanical models are used for individual conditioning/adaptation of the loads, their derivation shall be documented. This should preferably be done in pictorial form with the aid of sketches or (modified) assembly drawings. The results shall be presented as partial or interim results (see Section 5.A.5.4.2).

(11) As substantiation of the dimensions and eccentricities used in the computational analyses and of the mechanical boundary conditions and simplifications on which the calculations are based, the following shall be appended to the documentation:

- assembly drawings and sectional drawings which show the geometry clearly
- production and material specifications (for checking the design limits and the analysis hypothesis)
- individual parts drawings and/or type sheets of adjacent components, as well as the spring characteristics of connected elastomer bushings the data of which were used in the analyses

Note:

If the documents were submitted separately within the scope of certification for adjacent components or structures, it shall suffice to name the title, reference *number and revision number of the relevant document.*

5.A.5.3 Special requirements for the documentation

(1) The following requirements shall be applied especially for the documentation of FE analyses. This section is concerned with the input data, whilst Section 5.A.5.4 addresses the presentation of results. Insofar applicable, the documentation shall contain the following data:

- identification of the program used (name, variant and version designation; if applicable, designations of various software packages for pre-processing, post-processing and the solution phase)
- clear presentation of the inputs for the actions on the mechanical structure model. Apart from the loads named in Section 5.A.5.2, para 9, actions include in particular temperatures, prestresses and, if applicable, imperfections.
- description of the model through naming or presentation of the following:
    - the elements used (1D, 2D, 3D elements; naming of the element approach; contact and mass elements)
    - the additional element options (e.g. plane stress approach, axial symmetry)
    - the additional element constants (e.g. moment of inertia, definition of cross-section, element thickness)
    - the material values (e.g. elastic, plastic; friction coefficient)
    - the meshed FE model from all relevant perspectives, to demonstrate the level of detail and to clarify the support and boundary conditions. Here details shall be portrayed with a zoomed perspective and/or sections of the model (e.g. internal view).
    - all geometric simplifications. Neglected drill-holes, cut-outs, radii etc. shall be stated and justified with reference to the results.
    - the load introduction (as single, area or volume loads), according to position, size and direction of effect
    - the coupling conditions, mergings and the contact elements
    - the elements used for implementing bolt and spring prestressing
    - options used in the model but not listed until now, with justifications

(2) The inputs on which the calculations are based shall be prepared in one of the programs and documented in an appropriate number of overall and partial presentations. These inputs shall be shown in graphic form. They may only be printed out in tabular form if the overview and clarity of the data set cannot be improved considerably by a graphic presentation. It is important that any necessary supplements and explanations (even in handwriting) be appended.

5.A.5.4 Results

5.A.5.4.1 General

(1) The results can generally be divided into the partial and final results.

(2) If numerical results are to be processed further, it shall be observed that the accuracy of the overall result can depend strongly on the quality of the model.

5.A.5.4.2 Partial results

(1) Partial or interim results shall be used in the documentation for checking the plausibility of the input data (see Section 5.A.5.3).

(2) As and where applicable, the following partial results shall be documented:

- assessment of the mesh quality (in the highly-stressed regions)
    - through representation of the elements in the FE model with high distortions, warping and inadmissibly narrow or wide angles of the element edges
    - through error estimations of the elements (e.g. by means of energy hypotheses)
    - by stating the results of sensitivity studies with modified meshing of the entire FE model or of a partial model, especially for complex systems
- The influence
    - of the load introduction (e.g. transmission of individual loads using auxiliary structures, bolt prestressing, spoke wheel / St. Venant’s principle)
    - of the symmetry conditions and coupling conditions used (St. Venant’s principle)

  - of the deviations and simplifications (radii, drill-holes, averaged stiffnesses etc.)

  shall be assessed with regard to the results of the most highly stressed regions using deformation checks in relation to the unit loads applied. For this, the representation of the principal stresses and strains and their directions is useful. These results shall be used as a basis of argumentation for the selected boundary conditions and simplifications.

- When using non-linearities, the connection between external load and the stress (i.e. structural response) shall be presented in graphic and tabular form (e.g. non-linear curve of the bolt stress versus the load for partial openings in the joints). Any linearizations undertaken shall be described.
- the assessment on the selection of evaluation regions (e.g. geometric notches) for the component or the structure. Here figures shall be used to indicate clearly the position in the meshed global model. Insofar applicable, lists of the stresses (strains) shall be given for these evaluation regions, at least with unit loads as the transfer factor (or transfer function).
- It shall be shown that the stress concentration in the submodel to be investigated exerts no influence on the result at the submodel edge (St. Venant's principle).
- a check of the equilibrium through an analysis using reaction forces
- quality assessment by comparison of the calculated masses of the FE model with the drawing specifications
- statement of the assessment data from the FE model (e.g. averaged or non-averaged element/node results)

(3) The calculation results shall be prepared in an adequate program and documented in an appropriate number of overall and partial presentations. These results shall be shown in graphic form. They may only be printed out in tabular form if the overview and clarity of the data set cannot be improved considerably by a graphic presentation. It is important that any necessary supplements and explanations (even in handwriting) be appended.

(4) For margin studies, it is permissible to use certified models and the transfer factors calculated therein.

(5) In the case of frequent structural repetitions, reference examples can be applied.

(6) The FE results, the models and CAD data (the preferred CAD formats being *.iges, *.stp and *.x_t) shall be submitted with the documentation on appropriate data media in generally readable form (i.e. no machine or program code, unless expressly permitted/requested by GL).

5.A.5.4.3 Final results

(1) The final result is the objective defined as per Section 5.A.5.2, para 5. Here this involves the results mentioned in Section 5.A.4.5. The results shall be documented separately from the viewpoint of the ultimate load and fatigue strength.

(2) Documentation of the general strength analysis:

- The results of the ultimate loads shall be presented, with comments, preferably as a combination of the unit loads. It shall be ensured that there is perfect correspondence between the loads and their representation in the graphics/lists.
- A comparison between the calculated (equivalent) stresses and the design value shall be documented in accordance with the specifications in Chapter 5.

(3) Documentation of the fatigue strength analysis:

- The results shall be presented with consideration of the provisions described in Chapters 5 to 7 and with reference to the global FE model or previously selected regions (e.g. critical cross-sections, hot spots).

Appendix 5.B Calculation of Synthetic S/N curves

5.B.1 General

(1) In general, statistically assured and representative S/N curves for the raw material should be used as a basis for the fatigue analysis. If such S/N curves are not available for the material to be used, synthetic S/N curves may be used.

(2) This Appendix is meant to specify the calculation of synthetic S/N curves and the necessary extent of documentation.

(3) The procedures depicted in the flow charts of this Appendix are applicable for non-welded forged and rolled parts, cast steel and spheroidal graphite cast iron.

(4) The fatigue verification shall be carried out by using S/N curves that correspond to the local qualities of the component. The quality-related upgrading factors shall be chosen in accordance with the specified quality (e.g. j and j0; see Section 5.3.3.5.3). If the quality is defined differently in specific areas of the component, it shall be assured that areas of different quality grades are covered by the analysis.

5.B.2 Documentation

5.B.2.1 Documentation of input parameters

The documentation of input parameters shall be performed on the basis of Table 5.B.1.

Table 5.B.1 Input parameters for the calculation of synthetic S/N curves

Symbol	Meaning	Unit	Value
R_m	Tensile strength	N/mm²	
$Rp_{0.2}$	Yield strength	N/mm²	
R	Stress ratio	-	
α_k ($\alpha_k = 1$ for structural stress approach)	Stress concentration factor	-	
n	Notch sensitivity caused by stress gradient influence and localized plastic deformation at the notch base	-	
R_z	Surface roughness	µm	
γ_M	Partial safety factor for material	-	
j	Quality level for component	-	
j_0	Constant for material and test method	-	
t	Wall thickness	mm	

5.B.2.2 Documentation of result parameters

The documentation of key parameters defining the synthetic S/N curve shall be performed on the basis of Table 5.B.2. A graphical presentation of the S/N curve shall be part of the documentation as well (cf. Fig. 5.B.3).

Table 5.B.2 Result parameters defining the synthetic S/N curve

Symbol	Meaning	Unit	Value
$\Delta\sigma_1$	Upgraded upper limit of fatigue life line (stress range)	N/mm²	
N_1	Number of load cycles at upper fatigue limit	-	
$\Delta\sigma_A^*$	Upgraded stress range at knee of S/N curve	N/mm²	
N_D	Number of load cycles at knee of S/N curve	-	
m_1	Slope of S/N curve for $N_1 < N \leq N_D$	-	
m_2	Slope of S/N curve for $N > N_D$	-	

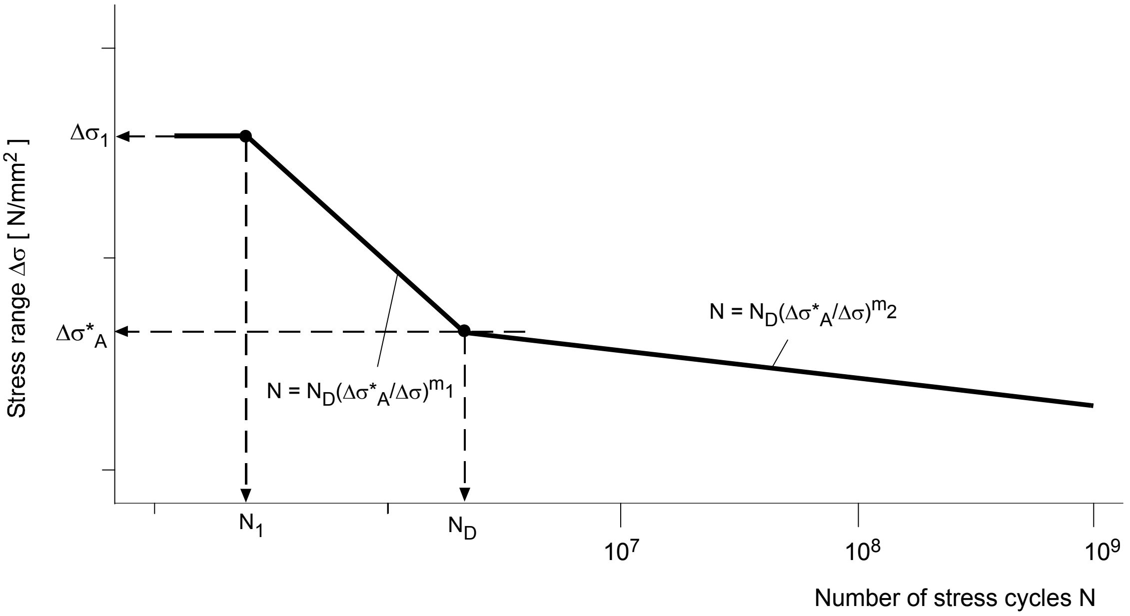
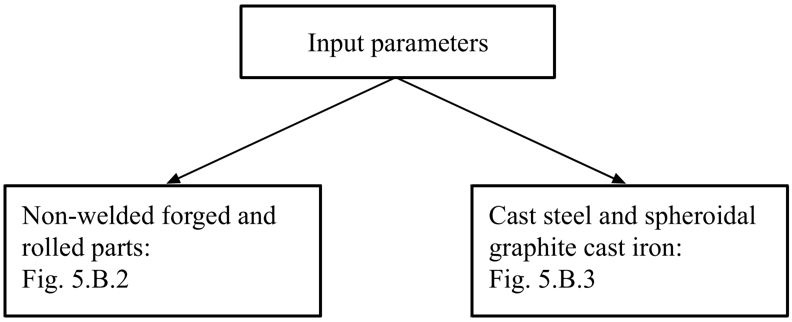


Fig. 5.B.1 Graphical presentation of the synthetic S/N curve

5.B.3 Calculation of S/N curve



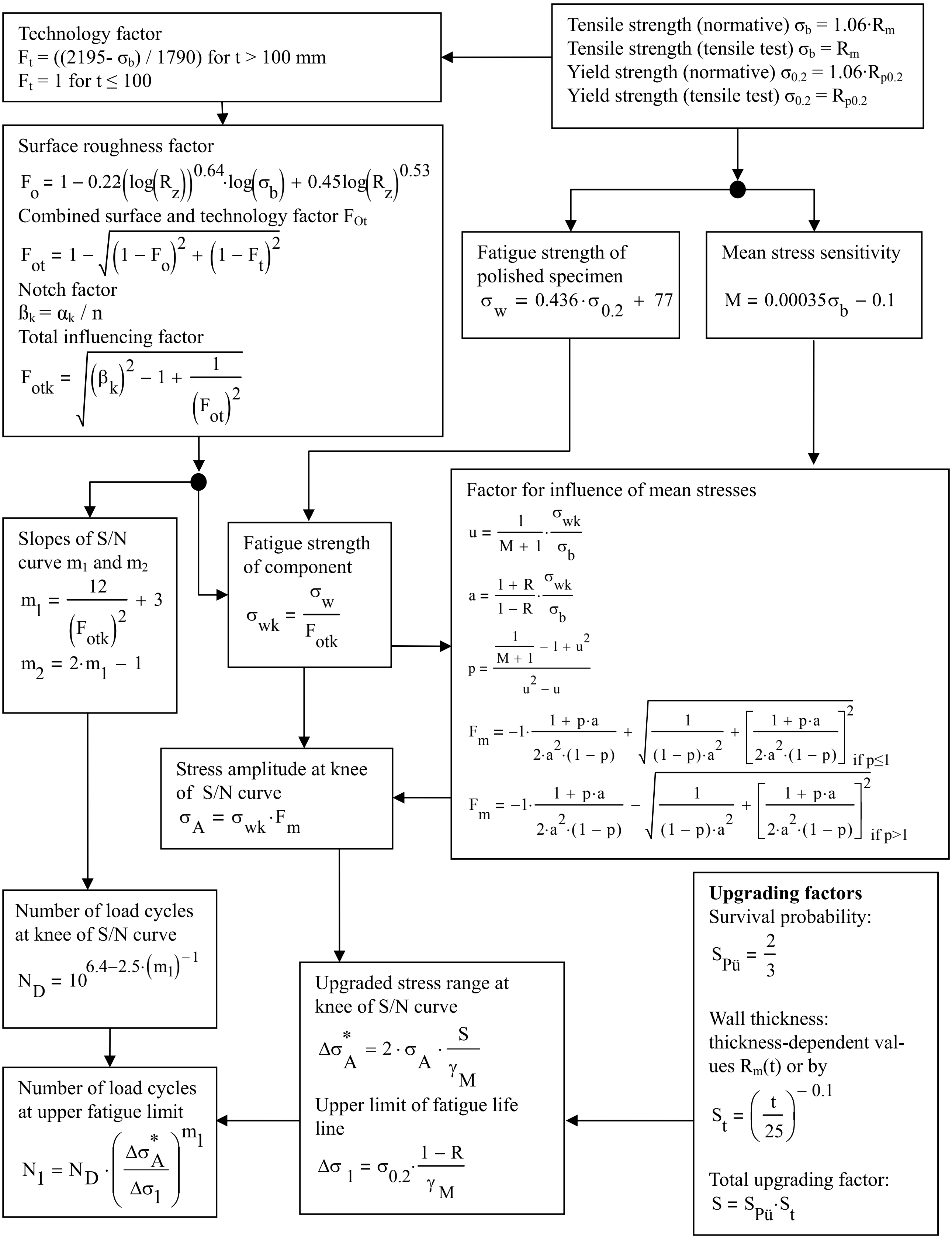


Fig. 5.B.2 Calculation of synthetic S/N curve for non-welded forged and rolled parts

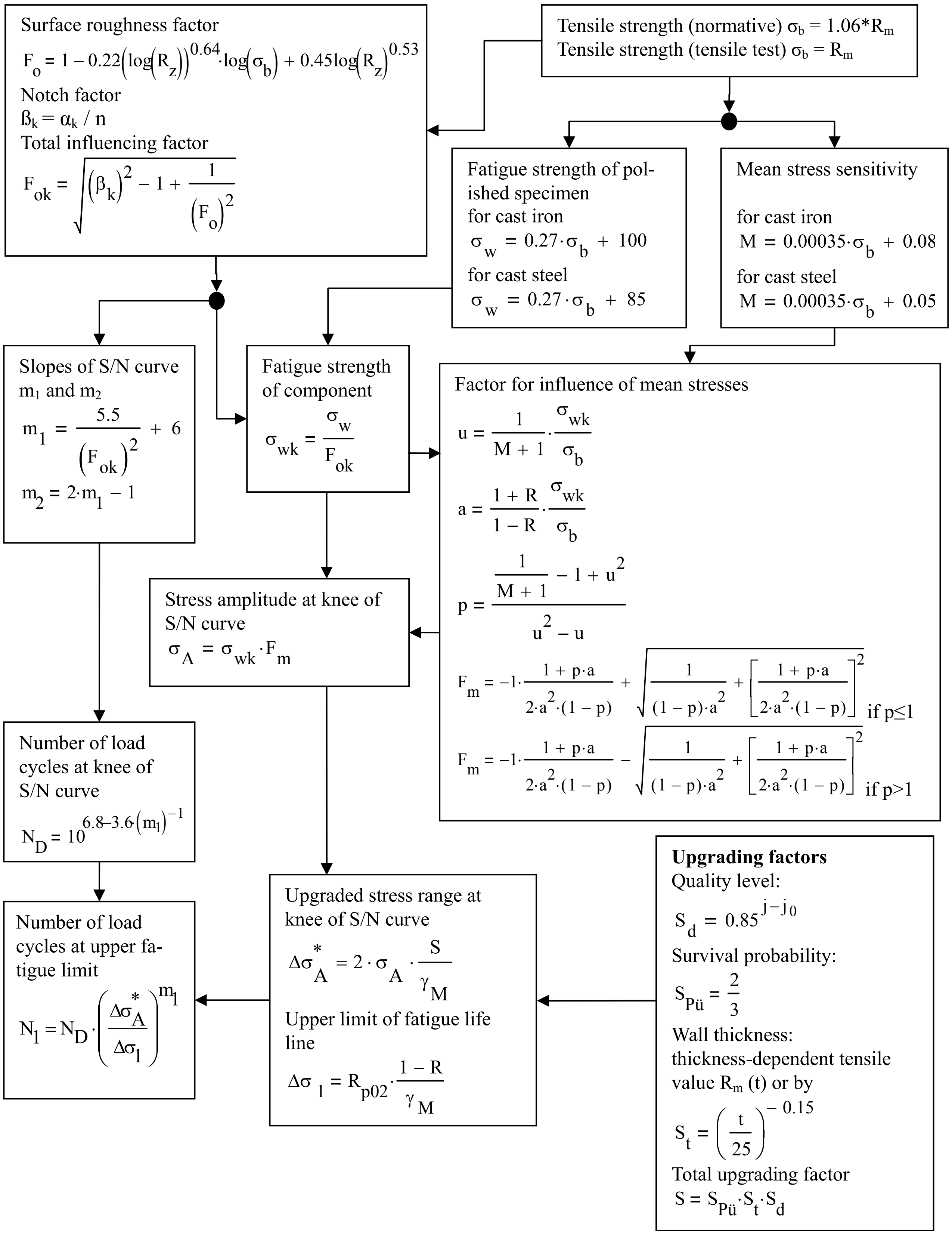


Fig. 5.B.3 Calculation of synthetic S/N curve for cast steel and spheroidal graphite cast iron

Rules and Guidelines
IV Industrial Services

1 Guideline for the Certification of Wind Turbines

6 Structures

Edition 2010

Table of Contents

6.1 General

(1) The term “structures” of a wind turbine in this Guideline refers to the load-bearing components. These include the rotor blades, castings, forgings and welded structures, nacelle cover and spinner, tower and foundation as well as bolts for connecting these structures. Machinery components are treated separately; see Chapter 7.

(2) The following sections of this Chapter explain the scope and type of the assessment documents to be submitted as well as the analyses to be performed for structures. Furthermore, the requirements for manufacturers, materials and final inspections are described, and reference is made to Chapter 3 where relevant.

(3) For the computational strength analysis, Chapter 5 shall be taken into account. The design loads (see Section 1.3.2.3, para 3) for the load cases determined according to Chapter 4 shall be applied.

(4) If the computational strength analysis incorporates characteristic values (e.g. friction coefficients) which were determined by tests, the following shall be observed:

- The tests shall be carried out by a laboratory accredited according to ISO / IEC 17025 or they have to be witnessed by GL.

- The interpretation of the test results shall incorporate a determination of the systematic error and a description of the random error (statistical interpretation).

Note:

If not otherwise demanded and a normal distribution of the test results is given, the statistical interpretation shall be carried out using a confidence level of $1\text{-}\alpha = 0.95$ *for a probability* $P = 95\ \%$ *and an unknown variance of the universe at least (e.g. DIN 55303, part 5, 1987).*

(5) Operations associated with moving or transporting a structure or parts thereof during the construction or installation may have a decisive influence on the overall design. These operations concerning the structural integrity are therefore included in the design review (Design Assessment and IPE).

6.2 Rotor Blades

6.2.1 General

6.2.1.1 Designs

(1) The strength and serviceability of rotor blades of most wind turbines with horizontal axes can be analysed on the basis of the contents of this section. Analysis of unusual designs shall be agreed with GL.

(2) Typical materials for rotor blades and connection components are fibre reinforced plastics (FRP) and wood. Strength analysis of rotor blades and blade parts made from these materials shall be carried out as per Chapter 5.

(3) The rotor blades shall be equipped with a suitable lightning protection system in accordance with Section 8.9.3.9. Proof shall be provided for the connection of the conductor cross-sections specified there to the blade structure. The lightning conduction arrangements shall be such that the blade-hub transition or other attachments are able to conduct the lightning current safely from the rotor blade to the tower.

6.2.1.2 Requirements for manufacturers

See Section 5.5.2.1.

6.2.1.3 Requirements for materials

See Section 5.5.2.2.

6.2.2 Assessment documents

a) documents for the material tests given in Section 5.5.4. The tests shall be performed by a test laboratory acknowledged according to Section 6.2.5.1, para 2.

b) written documents subject to assessment for the verifications set out in Section 6.2.4

c) detailed drawings that demonstrate the material lay-up comprehensively

d) drawings and specifications describing the production sequence in detail

e) coordinates of the profile cross-sections, in ASCII or MS Excel format

f) documents for the blade test (see Section 6.2.5)

g) load assumptions including definition of the coordinate system used

h) Data listed under items b), e) and g) shall be provided for a sufficient number of sections between the blade root and the largest local chord (usually 10) and at least 10 cross sections between the largest local chord and the blade tip.

6.2.3 Delivery checks

6.2.3.1 Final tests

(1) In addition to the quality controls during production, the manufacturer or someone appointed by him shall carry out final tests on a scale agreed with GL. The quality documentation applicable to the rotor blade type shall be submitted to GL (see Section 1.2.2.5.3).

(2) At least the checks listed below are required as part of the final tests for every blade:

- plausibility and completeness check of the data and entries in test sheets, control sheets, work-progress slips and check sheets which accompany the rotor blade through the production process
- check of the geometry including accuracy of profile data
- determination of the mass and the centre of gravity
- check of the balance quality for each set of blades; requirements as per Section 4.3.4.1, para 8

(3) The checks listed below are required as part of the final tests for at least one blade of a series:

- determination of the natural frequencies in flapwise and edgewise directions. In the event of large deviations in mass and centre of gravity, this shall be carried out for a number of blades.

6.2.3.2 Documentation

(1) On completion of the final tests a delivery document containing at least the following data shall be issued for each rotor blade:

- rotor blade type
- serial number and year of manufacture
- dimensions
- mass and centre of gravity
- type of aerodynamic brake, if applicable

(2) Each rotor blade shall be permanently marked with its serial number in an easily accessible position. Furthermore, an identification plate shall be attached with the following information:

- manufacturer
- type designation
- serial number

6.2.3.3 Defects

Deviations from the manufacturing processes shall be documented. If safety-relevant defects are detected during manufacturing surveillance, corrective measures shall be defined in consultation with GL.

6.2.4 Analyses

6.2.4.1 Analysis concept

(1) It shall be shown that the design values of the component resistances R_d are larger than the design values of the actions S_d . The strength of rotor blades shall as a rule be verified by an ultimate strength analysis and a fatigue analysis. Areas under compressive and/or shear loading shall be examined for stability failure (buckling, crinkling, wrinkling) through analyses in the ultimate limit state.

(2) In the case of component whose strength cannot be verified by the usual methods, special investigations are necessary after consultation with GL.

(3) For wind turbines with a rated output of up to 100 kW, a reduced scope of analysis is possible in consultation with GL.

(4) For rotor blades, the locations of greatest loading / damage and lowest safety (critical points) shall be shown for the decisive loads in each case, for both the extreme and fatigue strength analysis. If the location of these critical points and the type and magnitude of their decisive loading is not immediately clear, calculations shall be performed to provide this information. Particular attention shall be given to points with nonlinearities of the geometry and/or the material.

Note:

For sandwich structures, the Bernoulli hypothesis may not be applicable in every case. This has to be considered appropriately in calculation.

(5) In exceptional cases (e.g. for fatigue analysis), it is permissible by way of simplification to verify not the critical points but reference points with the applicable loads (e.g. points on the main axes or on axes of the chord coordinate system), from which conclusions can then be drawn on the safety of the critical points. The relationship of the minimum safety between the reference points and the critical points shall be verified adequately by means of fundamental investigations, sample calculations etc. For fatigue analysis, an extended examination is not required if a residual safety of 1.2 is given with regard to the flapwise and edgewise directions.

(6) Connections in the vicinity of local load introduction zones (e.g. tip shaft, metallic inserts at the blade root) shall be designed to be at least damage-tolerant. A construction is regarded to be damage-tolerant if an instance of damage does not lead to immediate failure of the structure.

(7) To ensure maintenance of a minimum clearance between the rotor blades and other parts of the plant, a deformation analysis shall be performed in the serviceability limit state. The deformation analysis shall be performed by dynamic and aeroelastic means. The clearance shall not be less than the minimum of 30 % for the rotor turning and 5 % for load cases with the rotor standing still, in relation to the clearance in the unloaded state.

6.2.4.2 Actions

(1) The loads on which the strength analysis of the rotor blades shall be based are listed in Chapter 4. The load cases determined by superposition of the external conditions with the operating conditions (design load situations) (see Section 4.3) shall be investigated and the dimensioning load cases (design load cases) shall be verified.

(2) It is generally sufficient to determine the envelopes of the extreme internal forces and moments as decisive actions.

6.2.4.3 Structural member resistances

The structural member resistances shall be determined according to Chapter 5.

6.2.5 Blade tests

6.2.5.1 General

(1) For the purpose of verifying the analysis, the rotor blades shall be subjected to tests of the natural frequencies and to full-scale rotor blade tests within the scope of the design assessment. The requirements for these tests are defined in the following.

(2) All tests shall either be performed by an acknowledged test laboratory (i.e. test laboratory accredited for the relevant tests according to EN 17025 or recognized by GL) or performed under the surveillance of GL. For all tests performed under the surveillance of GL, an approved test specification is needed; this shall be submitted in good time before the start of the test.

(3) Successful performance of the full-scale static blade test is considered as directly safety-relevant according to Section 1.2.2.4.1, para 3.

(4) Additional fatigue tests for complete blades, rotor sections or reference samples may be necessary. Possible indications for a necessary fatigue test are:

- blade design different from the state of the art
- damages revealed during operation
- exceptional deformation behaviour under operating loads (e.g. strong deformation of cross-section)

The requirements for this will be decided in each individual case.

6.2.5.2 Test requirements

(1) The rotor blade to be tested shall as a rule exhibit correspondence with the drawings and specifications submitted. If local reinforcements (e.g. in the area of the load introduction zones) become necessary because of the test, agreement shall be reached beforehand with GL. As part of the test report, correspondence of the test blade with the drawings and specifications submitted shall be certified or, failing that, the modifications shall be listed. Before the start of the test, the mass and centre of gravity of the rotor blade shall be determined and documented.

(2) As a rule, the tests shall be performed at least in the flapwise and edgewise directions, both positive and negative, of the blade. With regard to the maximum load occurring in the test, at least the test load S_{Test} shall be obtained for each point in the range from the root to 70 % of the blade length. In addition, the test shall be performed for the sections with the lowest residual safety. Here the influences on the loading from the deformation of the rotor blade shall be taken into account. After consultation with GL, the scope of the test may be reduced in justified cases. Furthermore, at least the first natural frequency of the clamped rotor blade shall be determined in the flapwise and edgewise directions. For rotor blades with a length of more than 30 m, it is additionally necessary to determine the second natural frequency in the flapwise direction, together with the first torsional natural frequency for torsionally soft ($f_{0,n,Torsion} < 5 \cdot f_{0,n,Flap}$) blades. In the case of rotor blades for stall-controlled turbines, the damping in the edgewise direction shall be measured.

(3) The test loading S_{Test} is determined as follows:

$$S_{Test} = S_d \cdot \gamma_{1T} \cdot \gamma_{2T}$$

where:

S_d = design values of the load

γ_{1T} = 1.1 for scattering of the rotor blade characteristics in series production

γ_{2T} = 1.0 for execution of the test with an ambient air temperature of at least 20 °C

= 1.1 for execution of the test with an ambient air temperature of -30 °C

The values between 20 °C and -30 °C may be interpolated linearly.

(4) In the following possibly critical areas, undisturbed loading is necessary:

- the part of the rotor blade from the blade root up to the profile section from which the cross-sectional properties only change slowly and continuously
- those parts of the rotor blade with the smallest calculated residual safeties against bulging or failure
- those parts of the rotor blade in which local reinforcements (e.g. for the blade tip brake) or other special design features are located

Without further analysis, it shall be assumed that there is no undisturbed loading over a length of 80 % of the local profile depth on both sides of a load introduction zone.

(5) Within the scope of the tests, at least the measurements listed below shall be performed. Here the results shall be determined for at least four load levels between 40 % and 100 % of the maximum test loading S_{Test} .

- The applied loads shall be measured at each load introduction point.
- The bending of the rotor blade shall be measured at least at half the rotor radius and at the blade tip.
- The strains of the girder in the upper and lower shell shall at least be measured at four cross-sections distributed over the test area as per Section 6.2.5.2, para 4.
- The strains of the leading and trailing edges shall at least be measured at the position of the maximum chord length and at half the blade length.
- The shear strains of the webs in the blade root area shall be measured, preferably at the point of greatest loading.

- The outside temperature shall be recorded during the test.

(6) Under certain circumstances, strain measurements may become necessary at other critical points. During the test, the corresponding load level shall be maintained for at least 10 seconds. Local failure or buckling during the test is not permissible without further analysis.

(7) It is recommended that rotor blades for wind turbines be tested together with their adjacent structures and so instrumented that the stress conditions of the bolted connections can also be determined.

(8) During the tests, the rotor blade lightning protection system should be installed in order to test it for operational demands (see Section 8.9.3.1, para 2). This is strongly recommended, as this is needed for assessment of the lightning protection according to Section 8.9.1. Before and after the tests, the condition of the lightning protection system (if present) shall be visually inspected and electrical conductor resistance shall be measured and documented in the report.

6.2.5.3 Documentation

(1) The loads and the loading set-up shall be described clearly in the test specification. In particular, the position and the magnitude of the load introduction as well as deviation between the actual and the required test load S_{Test} over the blade length shall be recorded. All measurements and measuring facilities shall be specified and the expected results shall be listed, whereby the maximum permissible deviations in the test shall be defined in relation to the precision of the calculations and measurements. Deviations of at most ± 7 % for the bending deflection, ± 5 % for the natural frequencies and ± 10 % for the strains are permissible as a rule. A test sequence plan and a specimen of the test records shall be appended.

(2) The test shall be documented in a report which describes clearly the test subject and the test procedure, lists the test results and assesses them with regard to the calculations. The test report should contain the following points:

- date and time of the test
- person responsible for the test
- description and characteristic data of the rotor blade
- documentation of production (if necessary in an annex)
- determination of mass, centre of gravity and natural frequencies
- description and derivation of the test load S_{Test} from the load simulations
- description of the test set-up and method of load introduction
- description of the measuring facilities
- calibration of the measuring devices
- precision of the measurements
- measurement parameters (forces, deflections, strains, temperature etc.)
- comparison of actual to required value for the test load S_{Test}
- comparison of calculated and measured values
- assessment of the measurement results

6.3 Machinery Structures

6.3.1 General

(1) The following applies especially to the force- and moment-transmitting machinery structures of a wind turbine, or of wind turbine components made of metallic materials as per Section 3.3.2.

(2) For the components listed below (if applicable), insofar as they are important for the integrity of the wind turbine and also present a danger potential for human health and life, a structural assessment is required.

- rotor hub
- rotor shaft and axis
- main bearing housing
- gearbox structures (e.g. torque arm, planet carriers and housing, if load-transmitting)
- torque arm
- main frame
- generator frame
- bolted connections

For the bolted connections playing a significant role in the transmission of loads, Section 6.5 shall be applied.

(3) Load-carrying structures for gearboxes, which are made of high-strength cast irons (non-ductile material, $A_5 < 12.5$ % and KV < 10 J) with spheroidal graphite, require an extension of the common design calculations by an adequate qualification procedure. The applicability of these structures has to be evaluated. The details of the qualification procedure shall be agreed with GL.

(4) GL reserves the right to extend the scope of the assessment accordingly for special structures of a wind turbine. For special structures, the scope of assessment shall be agreed with GL in advance.

6.3.2 Assessment documents

For assessment of the strength and serviceability of machinery structures of wind turbines, the following documents are required:

a) Data on the components with material properties, data from the manufacturer in the case of mass-produced parts, information about the standard in the case of standardized parts, notes on the specifications and drawings used etc. In addition, parts lists may be necessary in the case of welded structures.

b) Design documentation (assembly drawings, and if necessary working drawings and specifications), also of the primary adjacent components, executed in standard form and with clear identification (parts designation, drawing number, modification index), shall be submitted. These shall contain

   - in the case of structures of casting and forging materials, all necessary data on the delivery condition, such as surface finish, microstructure, heat treatment, corrosion protection etc.
   - in the case of welded structures, data on material designations, type of welding seam, heat treatment, corrosion protection etc.

c) For machinery structures which are contained in mass-produced parts and which have proved their suitability for use by successful service in comparable technical applications, type/data sheets are generally sufficient. Further documents or verifications are required for structures specially modified for the wind turbine.

6.3.3 Analyses

(1) Strength calculations shall verify the ultimate strength, fatigue strength and serviceability totally, clearly and confirmably for the machinery structures. They shall contain sufficient information on

- design loads
- static systems (analogous models) and general boundary conditions applied (also the influence of adjacent components)
- materials
- permissible stresses
- references used

(2) Requirements, verification and certificates for the materials are laid down in Chapter 3. Additional statements can be obtained from Section 5.3 and, if applicable, Chapter 7. The guidelines given in Chapter 4 with regard to the loads shall be observed.

(3) From the technical and calculation viewpoint, the documentation of the computational analyses shall form a unified whole together with all other documents (drawings, specifications). Here it shall be observed that the references of the adjacent components and structural areas which are mentioned in the computational analyses shall be included in the documentation. The formal and content-related requirements for the documentation of computational analyses for the certification of wind turbine components are set out as described in Appendix 5.A.5. The necessary scope may deviate from that described there.

(4) If the analysis concepts of different standards and guidelines are applied, these shall not be mixed.

6.4 Nacelle Covers and Spinners

6.4.1 General

6.4.1.1 Designs

(1) The strength and serviceability of the nacelle covers and spinners of wind turbines with a horizontal axis shall be analysed on the basis of the contents of this chapter. Analysis of unusual designs shall be agreed with GL.

(2) With regard to the lightning protection system for nacelle covers and spinners, see Section 8.9.

6.4.1.2 Requirements for manufacturers

Standard workmanship procedures shall apply; see e.g. Sections 3.4.3 and 3.4.4.

6.4.1.3 Requirements for the materials

(1) For general requirements, see Chapter 3, and for fibre reinforced plastics (FRP), see Section 5.5.2.2.

(2) For fibre reinforced plastics (FRP), the following shall apply in deviation from Section 5.5.2.2: The strengths and stiffnesses of the materials used shall be sufficiently known in each case, i.e. modulus of elasticity (E-modulus), Poisson's number, failure strain and the failure stress of the typical laminates used, both for tensile and compressive loading parallel and transverse to the fibres and for shear. Material tests are not required; the moduli, strengths and stiffnesses can be taken from the material specifications of the manufacturer or from the literature. The manufacturer shall verify that the characteristic values on which the analyses were based (see Section 6.4.3) are fulfilled for running production.

6.4.2 Assessment documents

a) written documents subject to assessment for the verifications set out in Section 6.4.3

b) drawings and documents describing the design

6.4.3 Analyses

6.4.3.1 Analysis concept

(1) It shall be shown by calculation or testing that the design values of the resistances R_d are larger than the design values of the actions S_d . Global forces and load introductions from attachments shall be taken into account and traced to the primary structural members (e.g. main frame, hub). For fibre reinforced plastics (FRP), the following applies:

- In the case of verification by testing, the action S_d shall be increased by test factors analogously to Section 6.2.5.2, para 3.
- The analysis for inter-fibre failure may be omitted.

(2) As actions, only the extreme loads need to be applied as a rule.

(3) If no appropriate calculation method exists for verification of some structural members (e.g. holding eyes or guard rails as protection against falling that are connected to FRP), tests are required for verification. The tests shall be performed by an acknowledged institution (i.e. laboratory accredited or recognized by GL) or under the surveillance of GL.

(4) For the analysis of the serviceability limit state, a precise analysis may be dispensed with. It is recommended that the maximum bending deflection of a structural member under characteristic loads shall not be larger than 1/200 of its maximum free span (for frames or cantilevers: 1/150).

6.4.3.2 Actions

Actions according to this section are defined as characteristic loads (F_{sk}, p_{sk}). Partial safety factors shall be applied as mentioned in the relevant paragraphs.

6.4.3.2.1 Dead weight

(1) In general, the values from Eurocode 1 shall be used. If the material used is not tabulated, 1.05 times the mean values (as an estimate of the characteristic values) of the manufacturer's figures shall be used for the case that the characteristic values are not expressly stated. In the event of contradictions or non-availability of individual values, the following priority shall apply:

- 1.05 times the mean values according to the manufacturer
- Eurocode 1

(2) For dead weight, the partial safety factor γ_F as per Chapter 4 shall be chosen.

6.4.3.2.2 Live loads

(1) Landings, floor plates, walkable cover parts inside, platforms etc.:

p_{Sk} = 3 kN/m²

F_{Sk} = 1.5 kN on 20 cm x 20 cm

(2) Roof loads, walkable cover parts outside:

p_{Sk} = 3.0 kN/m²
The total load on the roof can be reduced through appropriate labelling on site (e.g. notice at the exit hatch).

F_{Sk} = 1.5 kN on 20 cm x 20 cm

(3) Horizontal loads on all structural elements which are intended to offer horizontal resistance (height H of the load application over the floor or standing level = 1.1 m, load distribution width 20 cm or 20 x 20 cm pressure area for large-area nacelle covers):

p_{Sk} = 1.0 kN/m

F_{Sk} = 1.5 kN in every direction

(4) The least favourable load in each case shall be decisive.

(5) Holding eyes and guard rails as protection against falling (for personal safety, to be marked in a striking colour):

F_{Sk} = 20 kN in every direction in which forces due to falling can occur

(6) The values given above are minimum values. If guidelines or regulations applying at the installation site of the wind turbine (e.g. national labour safety regulations) demand higher values, these shall be authoritative.

(7) Partial safety factor for live loads: γ_F= 1,5

(8) Partial safety factor for holding eye load: γ_F = 1.0 (may be verified against the failure load)

6.4.3.2.3 Wind loads

$F_{Sk} = \rho/2 \cdot v^2_{Wind} \cdot A \cdot c_p$ (Wind is an external event; gust reaction factors can be neglected.)

where:

ρ air density as per Chapter 4

v_{Wind} according to Chapter 4,

DLC 6.1 (50-year gust with an airflow within a sector of ± 15° from the front with γ_F = 1.35),

DLC 6.2 (50-year gust from all sides with γ_F = 1.1 for grid failure without energy buffer for the yaw drive) or

DLC 7.1 (annual gust from all sides with γ_F = 1.1 for grid failure with energy buffer for the yaw drive)

A reference surface of nacelle cover and spinner

c_p The provisions of Eurocode 1 may be applied. By way of simplification, the assumptions given in Fig. 6.4.1 and Table 6.4.1 are permissible.

(1) The c_p values are chosen in such a way that the vertical airflow represents the decisive case for each surface.

(2) The assumptions for c_p apply for nacelles with sharp edges. For rounded shapes, all c_p values can be reduced by 20 %. Rounded shapes are those for which the radius of curvature for the corner represents 10 % of the corresponding surface exposed to the wind (intermediate values can be interpolated linearly).

(3) Partial safety factor for wind loads: γ_F as per DLC 6.1, 6.2 and 7.1 from Chapter 4.

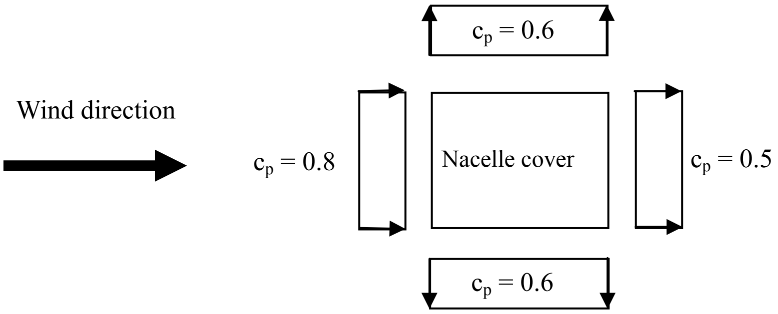


Fig. 6.4.1 Simplified c_p values assumed for a nacelle

Table 6.4.1 Simplified c_p values assumed for a nacelle

Aspect of surface A to the wind	Facing the wind	Facing away from the wind	Parallel to the wind direction
c_p	+0.8 (pressure)	-0.5 (suction)	-0.6 (suction)

6.4.3.2.4 Snow and ice loads

Snow and ice loads are included in the live loads on the nacelle roof. The loads were thus determined in Section 6.4.3.2.2. If guidelines or regulations applying at the installation site of the wind turbine (e.g. national labour safety regulations) demand higher values, these shall be authoritative.

6.4.3.2.5 Load combinations

The following load combinations shall be investigated:

- The dead weight shall be superposed with the live loads.
- The dead weight shall be superposed with the wind loads such that the least favourable cases are covered.

6.4.3.3 Component resistances

The component resistances R_d shall in general be determined in accordance with Chapter 5; plastic reserves and large displacements may be utilized.

6.5 Bolted Connections

6.5.1 Assessment documents

For the assessment of bolted connections, at least the following documents shall be submitted:

a) design calculations of the bolted connections according to the Sections 6.5.2 “Strength analyses of bolted connections”, 6.6.7.1 “Ring flange connections” and 6.6.7.3 “Shear-loaded bolted connections”

b) work instruction for making the bolted connection (assembly instructions). These instructions shall contain at least the following:

   - pretreatment or checks of the surfaces to be joined
   - If additional activities at the flanges (e.g. underpinning) during the connecting work are already intended in the design, these shall be described together with the necessary materials. If these activities only become necessary when certain criteria are exceeded (e.g. maximum gap widths), the criteria and measurement procedures shall be stated.
   - lubrication condition of thread and bolt/nut
   - tightening procedure and all data needed for manufacture (e.g. preloading, torque required, tightening tool)
   - tightening sequence

c) work instruction for checking the bolted connection (maintenance instruction), with statement of at least the test intervals and test procedure; see Section 6.5.3

d) drawings and specifications providing the remaining parameters for the design of the bolted connection, such as:

   - dimensions and tolerances
   - data on possible coatings of the flange surfaces or parts thereof
   - designation of the bolts, nuts and any washers
   - corrosion protection

6.5.2 Strength analyses of bolted connections

(1) Bolt calculations shall be performed on the basis of VDI 2230, Part 1 [6.1] (machinery components), DIN 18800 (tower and foundations) or other codes recognized by GL.

(2) For bolted connections with non-uniform stiffness of the adjacent parts and low stress reserve, a numerical analysis may be required in addition to the analytical analysis.

(3) Numerical analysis or experimental tests shall be performed if the above-mentioned standards are not applicable (e.g. for stress determination).

(4) For dynamically loaded bolted connections, an adequate preloading is necessary. Influences from the loading eccentricity, possible gaps in the joints and imperfections shall be taken into account. Here the finite element method may be used (see also Chapter 5, Appendix 5.A “Strength Analyses with the Finite Element Method”).

(5) Bolted connections that are dynamically loaded in the axial direction shall transmit shear forces by friction grip at the interfaces.

(6) The detail category to be used as a basis shall be applied in accordance with Section 5.3.3.5.1, para 11. For bolted connections subjected to dynamical loading, only the property classes 8.8 and 10.9 (according to ISO 898-1:2009) are permissible for the force- and moment-transmitting connections in the wind turbine.

(7) In design calculations for the static strength analysis of bolted connections at machinery components done in accordance with Section 5.3.2.1, para 5, and VDI 2230, Part 1 (see Section 6.5.2, para 1), the partial safety factor for the bolt material may be set to: $\gamma_M = 1.0$ if the torsional loading on the bolt as well as the tensional and bending loading is taken into account in the calculations. This does not influence the requirements on fatigue analysis in other sections of this Guideline.

(8) All friction coefficients that are used in calculations shall be verified, either by established written sources or by tests. The tests shall be carried out by accredited laboratories according to ISO/IEC 17025 or shall be witnessed by GL.

(9) The technique of tensioning bolts beyond the area of the elastic material shall be agreed in detail with GL. At least the following requirements shall be considered. These requirements are valid for both the case of yielding during the tensioning process (at the installation/mounting) and the case of yielding due to an extreme load during the operational life of the bolted connection.

(10) The plastic deformation during the tensioning process shall be determined in that section of the bolt where the yielding occurs most heavily (mostly the tensioned part of the free thread). For this the most unfavourable values of all data (data of the tensioning process, frictional coefficients, material data of the bolts material, etc.) shall be considered.

(11) The amount of plastic deformation during the occurrence of a possible extreme load shall be determined if the calculations show that such plastification is to be expected. For this the most unfavourable values of all data shall be considered.

(12) The plastification during the tensioning as per item a. above shall be added to the additional plastification during an extreme load as per item b. above. This sum (total plastification) shall be lower than or equal to 1 % of the length of that section of the bolt exposed to yielding. In this context, the partial safety factor for materials shall be: $\gamma_M = 1.0$.

(13) The minimum pre-tensioning force in the bolt shall be determined (calculations or tensioning tests/measurements) according to the tensioning procedure. A possible occurrence of an additional plastification during an extreme load (see item b. above) might reduce the tensioning force in the bolt and shall therefore be considered accordingly. For this the most unfavourable values of all data shall be considered.

(14) The minimum pre-tensioning force determined as per item d. above shall be reduced by 10 % to account for inaccuracies. This reduced pre-tension shall be used for the bolt fatigue calculation and the considerations of proper function of the bolted connection.

(15) When choosing the detail category as per Section 5.3.3.5.1, para 11, the values for “bolts rolled before heat treatment” (detail category 50 or 71) shall be used.

Note:

Limitations within national requirements shall be considered additionally in the case of tensioning bolts beyond the area of the elastic material.

6.5.3 Inspection of bolted connections

(1) During the operating life of the wind turbine, the bolted connections shall be tested as part of maintenance. These tests shall be specified in the maintenance manual (see Section 9.4). Here the following paragraphs shall be observed.

(2) All bolted connections that were tightened using a torque-controlled or tensioning-force-controlled method shall be retightened once after the commissioning. The original tightening torque or the original tensioning force on the bolts should be applied. The retightening time shall be specified.

(3) An interval for regular visual inspections and looseness checks during the life cycle of the wind turbine shall be specified. The intention of looseness checks is to detect if bolts have failed or have not been tightened.

(4) In the case of bolted connections which were tightened by other methods or which were brought into the plastic zone when tensioned, special inspection procedures shall be defined for each individual case.

(5) In the case of bolted connections for which GRP, CRP or concrete is included in the tensioned material, special inspection procedures shall be defined for each individual case.

6.6 Tower

6.6.1 General

The analyses are performed with the aid of the ultimate and serviceability limit states in accordance with Section 6.6.6.

6.6.2 Assessment documents

6.6.2.1 Calculation documents

The calculation documents serve to document the computational analyses. They shall be structured to be complete, comprehensible and clear.

6.6.2.2 Drawings

True-to-scale working drawings shall be produced to contain all the necessary information and technical requirements. These include in particular:

- representation of the tower geometry, including a general view
- detailed presentation of the design details
- material specifications
- welding seam specifications and acceptance criteria
- tolerance data
- specifications of the corrosion protection system

6.6.2.3 Description of erection

A brief description of the erection sequence, with the boundary conditions specific to erection, shall be appended to the assessment documents. Boundary conditions specific to erection include in particular:

- maximum wind speed for erection, if applicable
- min/max erection temperature, if applicable
- min/max interval between erection of the tower and mounting of the nacelle with rotor blades

Further requirements regarding the erection instructions are given in Section 9.1.

6.6.3 Analysis concept

For analyses of the components of the tower, the safety concept described in Chapter 5 shall be applied.

6.6.4 Loads to be applied

(1) The analyses shall be performed with the least favourable of all the combination of actions according to Section 4.3.3, Tables 4.3.1 and 4.3.2.

(2) For the analyses in the ultimate and serviceability limit states, both the characteristic loads and the design loads adapted by partial safety factors are needed.

(3) Additional loads resultant from imperfections and influences due to tilting of the tower and foundation should be considered as follows:

- 5 mm/m tilting of the tower for consideration of imperfections due to manufacturing and influences due to unidirectional solar radiation.

- 3 mm/m tilting of the foundation for consideration of unevenly subsidence of the ground.

6.6.5 Determination of the internal design forces and moments

6.6.5.1 General

(1) In general, the internal forces and moments for the dimensioning of tower and foundation shall be determined by means of an overall dynamic calculation with consideration of the provisions according to Section 6.6.5.2. Between the internal forces and moments determined in this way, it is permissible to interpolate linearly at arbitrary points.

(2) The natural frequencies of the tower shall be determined and specified for the vibration system to be investigated, assuming elastic behaviour for the material. The influence of the foundation shall also be taken into account. Dynamic soil parameters shall be used for the ground.

Note:

Particularly in the case of pile foundations, the rotation about the vertical axis and the horizontal displacement of the foundation shall be considered in addition to the rotation about the horizontal axis.

(3) The number of natural frequencies to be determined n shall be selected large enough so that the highest calculated natural frequency is at least 20 % higher than the blade transition frequency. In lattice support structures natural frequencies beyond this value may be relevant.

(4) In order to take account of the uncertainties in calculating the natural frequencies, they shall be varied by ± 5 % .

(5) In the case of turbines which do not satisfy equations 6.6.1 and 6.6.2 in continuous operation, i.e. are operated near the resonance range, operational vibration monitoring shall be performed; see Section 2.3.2.6.

$$\frac{f_R}{f_{0,n}} \leq 0.95 \quad \text{or} \quad \frac{f_R}{f_{0,n}} \geq 1.05 \qquad (6.6.1)$$

$$\frac{f_{R,m}}{f_{0,n}} \leq 0.95 \quad \text{or} \quad \frac{f_{R,m}}{f_{0,n}} \geq 1.05 \qquad (6.6.2)$$

where:

f_R	maximum rotating frequency of the rotor in the normal operating range
$f_{R,m}$	transition frequency of the m rotor blades
$f_{0,n}$	n-th natural frequency of the tower

6.6.5.2 Overall dynamic calculation

(1) The loads of the overall system shall be determined according to the elasticity theory by means of an overall dynamic calculation. It shall be noted that action components may also have a favourable effect for some analyses. The individual components of the internal forces and moments are generally not in phase, so that here the least favourable time step shall be picked out.

(2) For an overall dynamic calculation in the time domain, it is possible that the partial safety factor procedure cannot be applied. In this case, the procedure shall be as described in Section 1.3.3.

(3) The overall dynamic calculation yields time series of all internal forces and moments for the investigated load combinations in the relevant cross-sections. These are to be used for the design of tower and foundation. These internal forces and moments shall be determined for the analyses in the ultimate and serviceability limit states.

(4) For the analysis regarding strength and stability failure as well as for analysis in the serviceability limit state, it is permissible to state, by way of simplification, only the extreme values of the internal forces and moments together with the remaining internal forces and moments occurring simultaneously for the cross-sections investigated.

(5) For steel towers the internal forces and moments for the fatigue safety analysis may, as a simplification, be specified in the form of load spectra. For bolted connections and concrete towers the internal forces and moments for fatigue analysis shall be specified with load range and corresponding mean values, e.g. by specification of Markov matrices (see Appendix 4.B, Section 4.B.2.3).

6.6.5.3 Wind-induced vibration of the tower in the wind direction

(1) In analyses according to Section 6.6.5.1 for turbines in the “out of service” state, the vibration effect on the tower in the wind direction caused by the gustiness of the wind shall be considered through the application of an increased static load. When using the turbulent extreme wind speed model (EWM), the wind load resulting from the mean wind speed V(z) and acting directly on the tower in the wind direction shall be multiplied by the gust reaction factor G. An appropriate method for determining G is given in e.g. DIN 1055-4. By way of simplification, the building width b can be assumed to be 0.1 of the building height h. In the case of towers of preloaded concrete, reinforced concrete or steel, the value $\delta_B = 0.1$ may be assumed for the logarithmic decrement, which covers both the structural damping and the aerodynamic damping.

(2) If the steady-state extreme wind model (EWM) is used for calculating – on the basis of the 3s mean value (gust wind speed) – tower structures that are not vibration-prone according to DIN 1055-4, the gust reaction factor may be assumed as G = 1.

(3) In analyses according to Section 6.6.5.1 for turbines in the “in service” state, the vibration effect on the tower in the wind direction caused by the gustiness of the wind may be neglected, i.e. the gust reaction factor may be assumed as G = 1.

6.6.5.3 Wind-induced transverse vibrations

The loading on circular or near-circular towers arising from vortex-induced vibrations transverse to the wind direction can for example be determined by using the procedure in accordance with DIN 1055-4.

6.6.5.4 Internal forces and moments for the fatigue safety analysis

(1) The requirements for determining the internal forces and moments for the fatigue safety analysis are given in Chapter 4.

(2) If the fatigue safety analysis is performed on the basis of load spectra, then these shall be determined by computational means for the corresponding cross-sections through simulation of the decisive requirements for the fatigue, if necessary supported by load measurements; see Section 10.6. The ranges of the internal forces and moments shall be superposed in the least favourable manner.

(3) As a simplification, the spectra can be represented by envelopes (e.g. in trapezoidal form) of the load spectra obtained from the simulation. Here uniform load cycle numbers should be defined for all action components.

Note:

In general, consideration of the action components rotor thrust F_x*, tilting moment* M_y *and tower torsional moment* M_z *is sufficient. The tilting and tower torsional moments may be assumed to act with a phase difference of 90° to each other.*

6.6.5.5 Interfaces

(1) Within the scope of the calculation, the internal forces and moments at the nacelle/tower interface and the associated wind speeds and airflow angles shall be summarized in a table for the characteristic and the design loads. In the case of an aeroelastic calculation, the geometry, stiffnesses, natural frequencies and damping factors of the relevant complete system "tower with foundation" shall be specified in addition. The following shall be stated additionally for this interface:

- masses and moments of inertia for the machinery part of the wind turbine
- internal forces and moments of the load cases for the fatigue analysis of tower and foundation
- influences resulting from tower top eccentricities

(2) Regarding the tower/foundation interface, see Section 6.6.4.

6.6.6 Verification for the tower

6.6.6.1 Ultimate limit states

6.6.6.1.1 Safety concept

(1) The partial safety factors for the loads shall be determined as per Sections 4.3.5.2 and 4.3.5.3.

(2) The analyses shall be performed with the design loads for the least favourable of all combinations of actions of the groups N, A and T according to Section 4.3.3, Tables 4.3.1 and 4.3.2.

(3) The increase in the internal forces and moments as a result of nonlinear influences (e.g. second order theory, state II of concrete sections) shall be taken into account. It may be determined from a quasi-static calculation.

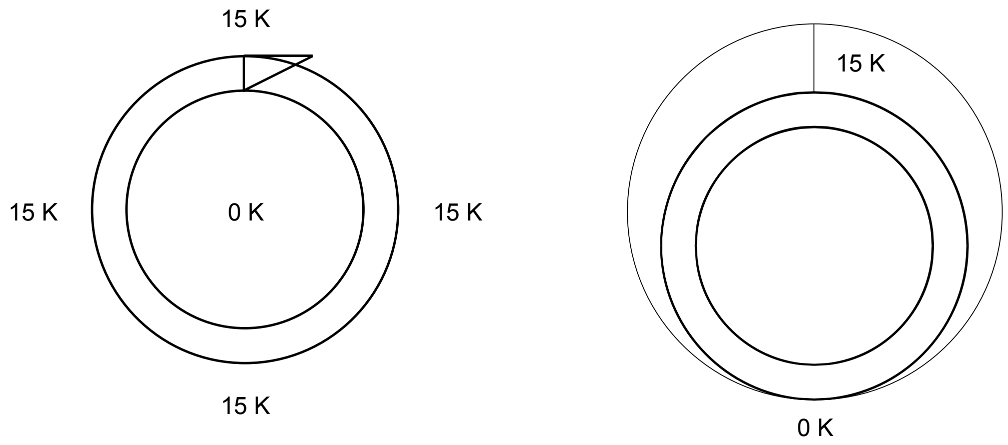
6.6.6.1.2 Ultimate limit state for strength

(1) For steel structures, the statements made in Section 5.3.2 shall be taken into account. For tubular steel towers with a cylindrical or conical shape, the stresses needed for the ultimate limit state verification may be calculated according to the shell membrane theory. This means, for example, that for the transfer of the wind loads the elementary pipe bending theory may be applied. Shell bending moments arising from wind pressure distributed unevenly over the tower circumference, or secondary stresses from edge disturbances at flanges or stiffeners, need not be taken into account. At transitions between cylindrical and conical tower sections, the local circumferential membrane forces and shell bending moments arising from the force deflection shall be taken into account, insofar as no ring stiffeners are arranged there. If this is not the case, adequate dimensioning of the ring stiffeners shall be verified. For tower areas that are weakened by openings, Section 6.6.7.2 shall be observed.

Note:

The analysis procedure described here corresponds in the terminology of DIN 18800-1 to an elastic/plastic analysis for the local internal forces and moments of the tower wall, but to an elastic/elastic analysis for the global internal forces and moments of the tower.

(2) Structures of reinforced concrete and preloaded concrete shall be verified in accordance with Section 5.4.2.1. Here the internal forces and moments of the tower shaft may be determined according to the pipe bending theory, provided that the wall thickness is at least 1/20 of the radius. This does not apply to local analyses in the vicinity of tower openings. To determine the loading resulting from heat influences on towers made of reinforced or prestressed concrete, a temperature component of $\Delta T_M = 15$ K acting uniformly over the circumference and varying linearly through the wall thickness shall be combined with a temperature component of $\Delta T_N = 15$ K acting with a cosine distribution over a circumferential sector of 180° and remaining constant through the wall thickness (see Fig. 6.6.1).



Temperature gradient along the wall thickness

Temperature gradient along the circumference

Fig. 6.6.1 Temperature gradients for a concrete tower

6.6.6.1.3 Ultimate limit state for stability

(1) For the stability analyses of steel structures, e.g. EN 1993-1-6 or DIN 18800, Parts 2 to 4, shall apply. In the simplified buckling safety analysis of tower sections as “long cylinders” according to equation (29) of DIN 18800-4:1990-11, equation (30) of DIN 18800-4:1990-11 may be replaced by equation (6.6.3):

$$C_x = 1.0 \cdot \frac{\sigma_{x,M}}{\sigma_x} + C_{x,N} \cdot \frac{\sigma_{x,N}}{\sigma_x} \tag{6.6.3}$$

where:

σ_x	meridional stress
$\sigma_{x,N}$	component of the meridional stress from the tower perpendicular force
$\sigma_{x,M}$	component of the meridional stress from the tower bending moment
$C_{x,N}$	coefficient C_x acc to DIN 18800-4:1990-11 (408) as per equation (30)

The above formulation applies for

$$r/t \leq 150$$

$$\frac{l}{r} \cdot \left(\frac{t}{r}\right)^{0.5} \leq 6$$

and for structural steel types S 235 to S355 or equivalent

where:

l	length of shell segment
r	radius of the middle surface
t	wall thickness

(2) The buckling safety analysis may also be performed as a “numerically supported buckling safety analysis with global calculation”, e.g. with the aid of finite element analyses. A prerequisite for this is that the application conditions for the specific variants named in Sections 8.6 to 8.8 of EN 1993-1-6:2007 are considered.

(3) The stability analysis for the buckling and bulging of structures made of reinforced concrete and prestressed concrete can be performed according to e.g. Eurocode 2, EN 1992-1-1, Section 5.8.

6.6.6.1.4 Ultimate limit state for fatigue

(1) The analyses shall be performed with the combination of actions of group F according to Section 4.3.3, Tables 4.3.1 and 4.3.2.

(2) For steel structures, the statements made in Section 5.3.3 shall be taken into account. Regular maintenance and the Periodic Monitoring according to Chapter 11 are regarded as prerequisites.

Note:

The towers of wind turbines as a rule contain components that are solely not fail-safe. Easily accessible components are e.g. the bolts of ring flange connections and butt welds in the tower wall.

(3) Structures of reinforced concrete and prestressed concrete shall be verified in accordance with Section 5.4.2.2.

(4) Regarding the selection of S/N curves for steel structures, see Section 5.3.3; regarding concrete, reinforcing steel and prestressing steel, see Section 5.4.2.2.

6.6.6.1.5 Wind-induced transverse vibrations

(1) Damage contributions from wind-induced transverse vibrations D_Q shall always be taken into account. Here the damage contributions from the two states "standstill with machine mounted" $D_{Q,1}$ and "tower standing without machine" $D_{Q,0}$ shall be calculated as per Section 6.6.5.3.

(2) When calculating the damage contribution $D_{Q,1}$, a standstill period of 1/20 of the operating life shall be applied.

(3) When calculating the damage contribution $D_{Q,0}$, the time the tower stands without machine shall be specified by the manufacturer and taken into account in the calculation. The damage contribution $D_{Q,0}$ shall only then be taken into account if the time the tower stands without machine exceeds one week. For a non-verified standstill time of up to one week, the wind speed shall be at most 90 % of the critical wind speed calculated when determining the internal forces and moments. If this is not the case, measures shall be taken against transverse vibrations.

(4) The damage contributions D_Q do not need to be accumulated with the damage contributions of the actions from the operating states D_F if the wind direction for the determination of D_F was assumed to be constant for the entire action duration.

(5) If the wind direction distribution is taken into account when determining D_F, then D_F and D_Q shall be accumulated. Here the less favourable value of the two equations 6.6.4 and 6.6.5 shall be taken into account:

$$D = D_F \tag{6.6.4}$$

$$D = \frac{19}{20} \cdot D_F + D_Q \tag{6.6.5}$$

6.6.6.2 Serviceability limit state

(1) For the analyses in the serviceability limit states, the design values of the actions shall be determined using the characteristic values (see Section 4.3.5.1).

(2) For steel structures, the statements made in Section 5.3.4 shall be taken into account.

(3) Structures of reinforced concrete and preloaded concrete shall be verified in accordance with Section 5.4.3.

(4) In supplement to Section 1.3.2.2, some examples of the limit states listed there are given below:

- The deformation limit state is for instance defined by the maintenance of a safety gap (distance rotor blade / tower or rotor blade / guy wire). It may also happen that thermal expansion becomes decisive.
- The vibration limit state is for instance defined by keeping vibration amplitudes or accelerations within acceptable limits. This limit state is usually enforced via the control system (see Section 2.3.2).
- The crack-formation limit state shall be observed in the case of concrete structures. Crack widths shall be kept within acceptable limits.
- The stress or strain limit state is for instance defined by the limitation of tensile and/or compressive stresses in concrete structures or the precondition that steel structures shall not undergo plastification under characteristic actions.

6.6.7 Design details

6.6.7.1 Ring flange connections

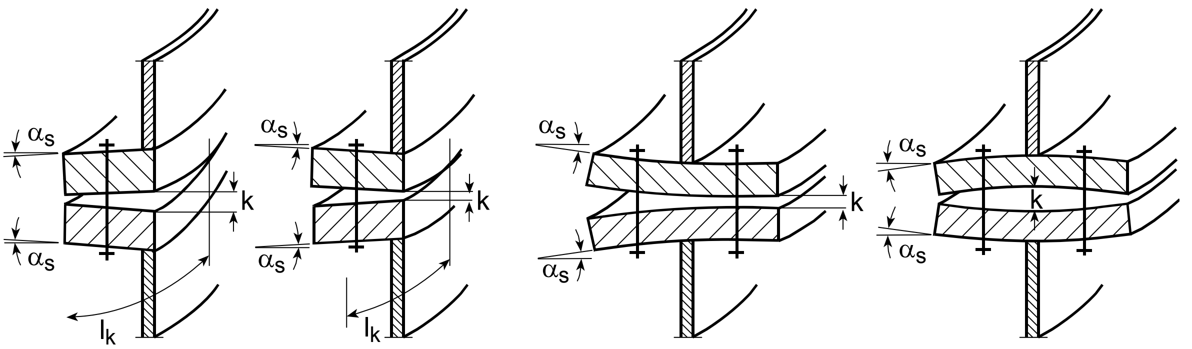
(1) Ring flange connections shall be controlled tightened, e.g. according to DIN 18800 Part 7.

(2) In the ultimate limit state analysis of the flange connections, the preloading force of the bolts need not be considered, i.e. the ultimate limit state analysis may be performed as for a non-preloaded bolted connection. Local plastifications (yield hinges in the flange and/or in the tower jacket) may be considered here.

(3) In the fatigue safety analysis of the flange connection, the fatigue loading of the bolts may be determined with consideration of the compressive preloading of the flanges, provided the following conditions are met.

(4) During the fatigue calculation, the maximum pretension force of the bolts shall be applied with 70 % of regular pretension force of the bolt. The pretension force of the bolts may be applied with 90 % of the regular pretension force, if during the six months after first installation, but not directly after the installation, the regular pretension is ensured by retightening of the bolts if necessary.

(5) Adequate compressive preloading of the flange contact surfaces may be assumed if the gaps between the installed flanges meet the tolerance values prescribed by the manufacturer with at most 10 % of the design preload. These shall be stated in the working documents, especially in the drawing.



a) L-flange, **b) T-flange**

Fig. 6.6.2 Ring flange connections in steel towers

Notes:

All flange gaps k in the area of the tower wall are damage-relevant for the fatigue loading of the bolts (see Fig. 6.6.1), particularly when they extend only over part of the circumference. The damage influence grows with decreasing spanning length l_k *over the circumference (Fig. 6.6.2).*

Instead of stating prescribed tolerance values for the flange gaps k at a maximum of 10 % of the design′preload, it is alternatively permissible to specify maximum values for the degree of preloading (referred to the design preload) in the working documents up to which all flange gaps k in the area of the tower wall shall have closed. These values shall be verified by computation.

(6) If the tolerance values specified in the working documents for the flange gaps are not complied with, suitable measures shall be taken. Suitable measures may e.g. include reworking, shimming or filling out the damage-relevant gap spaces before preloading takes place.

Note:

For the shimming of gap spaces, adapted shims shall be used for which the compressive strength (yield point under compression) at least complies with that of the flange material. If the shimming is implemented by stacks of thin sheeting, the fitting inaccuracy of the individual shims shall not be greater than 0.5 mm. The lining shall be executed such that, either in the direct vicinity of each bolt or in the area between each individual bolt and the tower wall (including the area directly under the tower wall itself), perfect pressure contact is produced already at the start of the preloading process, but at the latest after applying 10 % of the preload. For filling up the spaces, a filler material shall be used with an E-modulus complying with that of the flange material.

(7) If, after the preloading, the remaining inclination α_S of the outer flange surfaces (see Fig. 6.6.2) exceeds the limiting value of 2 % according to DIN 18800-7, Element 814, suitable taper washers with sufficient hardness shall be used instead of the normal washers.

Notes:

If the bolt force function is determined without imperfections with the aid of an ideal calculation method (e.g. FEM using contact or spring elements), the flange gaps tolerated in the execution of the work may be taken into account by a suitable increase in the initial gradient of the bolt force function.

As a substitute, a simplified calculation method (e.g. according to Petersen) may be used if it covers flange gaps of the magnitude tolerated in execution of the work.

Assured findings on the magnitude of the flange gaps covered by a simplified calculation method were not available on publication of this Guideline. Accordingly, the simplified calculation methods according to Petersen and Schmidt-Neuper may be used for the calculation of the ring flange connections until a revised version is published. When using calculation methods which do not consider the influence of the bending moment on the bolt, the fatigue safety of the bolt shall be determined using detail category 36.*

Calculations with the aid of the finite element method (FEM) that do not consider flange gaps, as well as other calculation methods leading to comparable results, are not permissible.

The calculation method according to Petersen and Seidel [6.2] may be used for ULS verification of ring flange connections.

6.6.7.2 Openings in tubular steel towers

(1) If the buckling safety of the tower wall in the area of an opening is to be verified with the aid of FE analyses, a "numerically supported buckling safety analysis with global calculation" (LA) or a "geometrically nonlinear elastic calculation (GNA)", e.g. according to EN 1993-1-6:2007, Section 8.6, shall be performed. Here the elastic critical buckling resistance R_{cr} shall be determined from a geometrically nonlinear elastic calculation (GNA). When deciding on the reference point for determination of the plastic reference resistance R_{pl}, the immediate area around the opening may be neglected; this immediate area shall not be set to be wider than $2(r{\cdot}t)^{0.5}$.

(2) In the area of edge-stiffened openings with added longitudinal stiffeners, the buckling safety analysis may be carried out in simplified form according to DASt Guideline 017. The design-related boundary conditions and validity limits specified for this shall be observed.

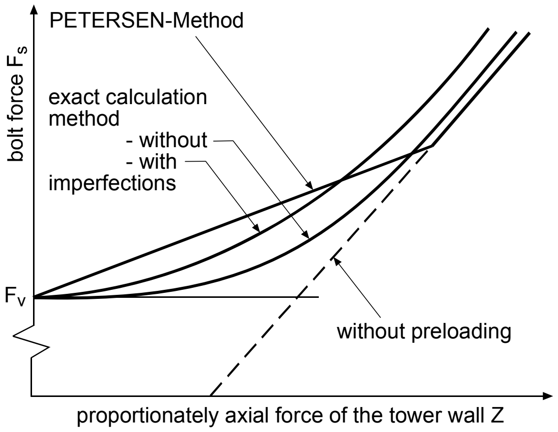


Fig. 6.6.3 Bolt force functions of preloaded ring flange connections

(3) In the area of circumferentially edge-stiffened openings without added longitudinal stiffeners ("collar stiffeners"), see Fig. 6.6.4 a) and b), the buckling safety analysis may in simplification be performed as for an unweakened tower wall if, instead of the critical meridional buckling stress according to DIN 18800-4, the reduced critical meridional buckling stress according to equation 6.6.6 is used:

$$\sigma_{xS,R,d} = C_1 \cdot \sigma_{xS,R,d\text{-DIN}} \qquad (6.6.6)$$

where:

$\sigma_{xS,R,d\text{-DIN}}$	critical meridional buckling stress according to DIN 18800-4,
C_1	reduction factor as per equation 6.6.7 to consider the influence of the opening.

$$C_1 = A_1 - B_1 \cdot (r/t) \qquad (6.6.7)$$

with A_1 and B_1 according to Table 6.6.1

where:

δ opening angle along the girth

The above rules are valid for

- tower walls with $(r/t) \leq 160$,
- opening angle $\delta \leq 60°$, and
- opening dimensions h_l / $b_l \leq 3$,

whereby the opening angle and opening dimensions refer to the cut-out of the tower wall without considering the opening edge-stiffener (see Fig. 6.6.4), and also for opening edge-stiffeners

- which exhibit a constant cross-section around the entire opening or are considered with their smallest cross-section,
- whose cross-section area is at least one-third of the missing opening area,

Table 6.6.1 Coefficients for equation 6.6.7

	S 235		S 355	
	A_1	B_1	A_1	B_1
$\delta = 20°$	1.00	0.0019	0.95	0.0021
$\delta = 30°$	0.90	0.0019	0.85	0.0021
$\delta = 60°$	0.75	0.0022	0.70	0.0024
Intermediate values may be interpolated linearly. Extrapolation is not permissible.				

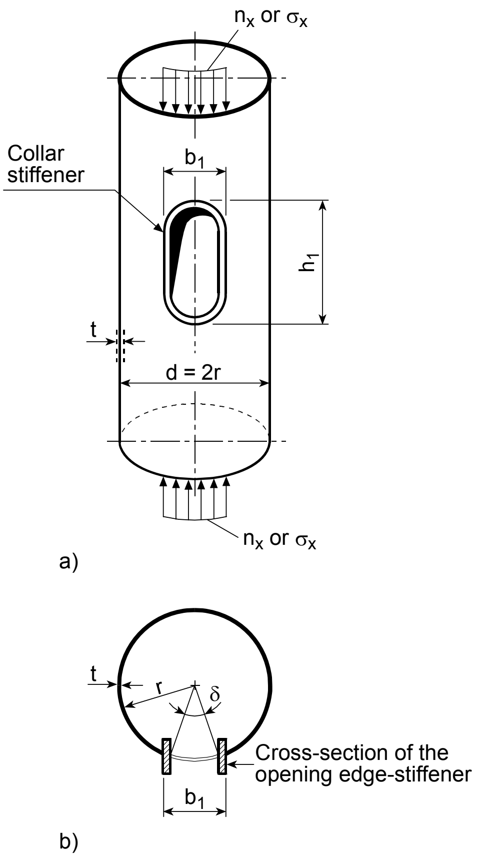


Fig. 6.6.4 **Circumferentially edge-stiffened opening**

– whose cross-section at the opening edges is arranged centrally with regard to the wall mid-plane (see Fig. 6.6.4),

– whose cross-sectional parts meet the limiting (*b*/*t*) values according to DIN 18800-1:1990-11, Table 15.

(4) For openings in tubular steel towers, the stress concentration at the opening edge shall on principle be considered in respect of the stress analysis as well as the fatigue strength analysis, in addition to the buckling safety.

6.6.7.3 Shear-loaded bolted connections

(1) Bolted connections at the joints and faces of components belonging to the primary supporting structure shall be executed as fitting shear connections (SLP, SLVP) or as slip-resistant preloaded connections (GV, GVP).

(2) In the case of SLP and SLVP connections, an analysis shall be performed for the perforated components and the bolts according to Sections 6.6.6.1.2 and 6.6.6.1.4. In the case of fitting connections with hot-dip galvanized components, special corrosion protection measures shall be taken.

(3) For GV and GVP connections, it shall be verified that the maximum force acting in the ultimate limit state on a bolt in a shear joint does not exceed the design slip resistance according to equation 6.6.8:

$$F_{s,Rd} = 0.9 \cdot \frac{\mu}{\gamma_{M,3}} \cdot F_V \qquad (6.6.8)$$

where:

F_V	regular preloading force according to DIN 18800-7. This preloading force shall be ensured by checking and if necessary retightening within the first half-year after erection, but not immediately following the commissioning.
$\mu \geq 0.5$	slip factor for the execution of the contact surfaces according to DIN 18800-7. For other versions, the slip factor shall be verified in accordance with Element 826 by a procedure test.
$\gamma_{M,3} = 1.25$	safety factor for combination of actions of group N and the operating conditions 1 to 4 according to Section 4.3.3, Table 4.3.1
$\gamma_{M,3} = 1.1$	safety factor for all other combinations of actions according to Section 4.3.3, Tables 4.3.1 and 4.3.2

(4) In addition, the analyses of ultimate limit state for the perforated components shall be carried out as well as for shearing-off and face bearing pressure.

Note:

Through these analyses, the analysis of fatigue safety is also covered.

6.6.8 Durability

Particular attention shall be paid to durability, as long intervals of time elapse between periodical inspections of the wind turbine structures. The basic principles for durable construction are set out e.g. in Eurocode 2, EN 1992-1-1, Section 4 or DIN 1045-1, Section 6 for reinforced and prestressed concrete structures; in DIN 18800, Part 1, Section 7.7, Eurocode 3 and DIN EN ISO 12944 for steel structures.

6.7 Foundation

6.7.1 General

(1) The nature of the soil is decisive for the type of foundation. Adequate knowledge of the soil shall be available before construction starts.

(2) The internal and external load-bearing behaviour, as well as dynamic and static analysis, shall be evaluated separately.

(3) Insofar as the foundation subsystem was replaced by torsion and displacement springs at the tower base when calculating the natural frequencies of the overall system, these assumed spring values shall be confirmed during the foundation calculation (torsional and horizontal stiffness of foundation and soil), e.g. by suitable approximation formulae.

6.7.2 Assessment documents

6.7.2.1 Calculation documents

(1) The calculation documents shall document the computational analyses. They shall be complete, comprehensible, clear and well structured.

(2) The origin of unusual equations and calculation methods shall be stated.

6.7.2.2 Drawings

True-to-scale design drawings shall be produced to contain all the necessary information and technical requirements. These include in particular:

- representation of the foundation geometry
- detailed presentation of the reinforcement (reinforcement drawings)
- material specifications
- requirements for the soil

The specification of turbine type and type class on the drawings is recommended.

6.7.2.3 Instruction for construction

An instruction for construction shall be provided, specifying all steps and procedures of construction. This instruction, drawn up by the foundation designer, shall be used to instruct the building contractor about all important design requirements for production.

6.7.2.4 Soil investigation report

For site-specific certifications, a soil investigation report shall be submitted. The report shall contain statements on:

- the ground with strata, faults, disturbances and inclusions
- groundwater conditions
- the soil and rock properties and parameters
- the boundaries of the investigated areas and their boundary conditions

GL reserves the right to determine in detail the scope of documentation to be submitted.

6.7.3 Analysis concept

(1) For the analyses of components made of reinforced concrete and prestressed concrete as well as components of steel, the safety concept described in Sections 5.3 and 5.4 shall be applied.

(2) For the soil (external load-bearing capacity), the concept of partial safety factors shall be applied. For the loads, the partial safety factors according to Table 4.3.3 shall be used. For resistances, the partial safety factors according to DIN 1054 shall be applied. Partial safety factors according to other standards may be used after consultation with GL if they lead to the same safety level as described before.

6.7.4 Loads to be applied

(1) The analyses shall be performed with the least favourable of all the combinations of actions according to Table 4.3.1.

(2) For the analyses in the ultimate and serviceability limit states, both the characteristic loads and the design loads adapted by partial safety factors are needed at the tower/foundation interface.

(3) Additional loads resulting from imperfections and influences due to tilting of tower and foundation should be considered according to section 6.6.4 Para 3.

6.7.5 Foundation

6.7.5.1 Structural steel components

Structural steel components shall be verified according to Section 5.3 or 6.6.

6.7.5.2 Reinforced concrete components

(1) Reinforced concrete components shall be verified according to Section 5.4.

(2) Areas of concentrated load introduction shall be considered.

(3) Areas of the foundation above an integration depth of 0.5 m in the earth shall be verified for a crack width of 0.2 mm, and all other areas for a crack width of 0.3 mm (see also Section 5.4.3.4).

(4) The assessment of water and soil for their aggressiveness to concrete can be carried out as per DIN 4030.

6.7.5.3 Design of piles

The internal load-bearing capacity of foundation piles shall be determined as set out in Sections 6.7.5.1 and 6.7.5.2. The analysis of the external load-bearing capacity of the piles shall be performed in accordance with Section 6.7.6.4.

6.7.6 Soil

6.7.6.1 Safety concept

(1) It shall be verified that the loading of the soil is smaller than the permissible values. This may be done according to DIN 1054.

(2) Here the loading from the characteristic values of the actions may be determined, whereby non-linear influences shall be taken into account analogously to Section 5.4.2.1, para 4. In order to obtain the design values for the loading of the soil, the partial safety factors for loads according to Table 4.3.3 may be applied on the characteristic loading.

Table 6.7.1 Assignment of combinations of actions according to Tables 4.3.1 and 4.3.2 to the load cases according to DIN 1054:2005-01

Load case according to DIN 1054	Combination of actions according to Tables 4.3.1 and 4.3.2 (DLC)
1	N, T
2	Construction conditions
3	A

(3) For the analysis as per DIN 1054, the load cases 1, 2 or 3 in the sense of DIN 1054:2005-1, 6.3.3 shall be assigned to the combinations of actions according to Tables 4.3.1 and 4.3.2 of this Guideline as per Table 6.7.1.

6.7.6.2 Nature of the soil

(1) It shall be ensured that the properties of the soil correspond to the assumptions in the static and dynamic calculation.

(2) Insofar as no soil investigation report is available yet when the foundation is designed, conservative assumptions shall be made for the soil, and these shall be confirmed by a soil expert before the start of construction.

(3) For the dynamic analysis, the distance of the natural frequency for the overall structure from the excitation frequencies is decisive in avoiding resonance. In the assessment of the expected natural frequencies, a parameter study is needed for the dynamic soil parameters; this shall be defined so that a range of possible soil types and soil properties is covered. The required minimum values for the shear modulus G of the soil may be specified as dynamic values according to DIN 4178:2005-04 in relation to the Poisson's ratio ν.

(4) The highest permissible water level shall be stated.

6.7.6.3 Slab foundations

(1) Slab foundations shall be verified against

- tilting (eccentricity of load / gaping joint)
- bearing capacity failure
- sliding
- buoyancy
- settlement

Verification can be in accordance with e.g. DIN 1054 or according to the following standards:

- Bearing capacity failure calculation
  DIN 4017
- Soil pressure distribution
  DIN 4018
- Settlement calculation
  DIN V 4019-100

(2) The analysis of sliding stability is set out in e.g. DIN 1054, Section 7.5.3.

(3) For the analyses in the ultimate and serviceability limit states as per DIN 1054, Section 7, the following procedure shall be observed:

- Permanent loads in the sense of DIN 1054, Section 7.6.1, are the actions of DLC 1.1 and 6.4 with a probability of exceedance of $p_f = 10^{-2}$ (equivalent to 1750 h in 20 years). Under these actions ($\gamma_F = 1.0$), a ground gap shall not occur.

Note:

For the permanent loads in the sense of DIN 1054, Section 7.6.1, the actions of DLC 1.1 and 6.4 which occur more than 10^4 times are recommended alternatively as a conservative approach.

(4) The forces resulting from the characteristic loads of load case 1, 2 and 3 according Table 6.7.1 ($\gamma_F = 1.0$) are only permitted to cause a ground gap up to the centre of gravity of the bottom area of the foundation.

(5) For load case 3, verification of safety against overturning may be omitted if the bearing resistance has been successfully verified.

(6) For separated foundations, e.g. for lattice towers, the foundation parts shall be verified against uplift with the partial safety factors according to Table 4.3.3 for all load directions. This verification may be omitted if the effects of the stress increase in the tower structure due to uplift of a foundation part are verified in the tower analysis and if verification against bearing failure and tilting is fulfilled by the remaining foundations.

6.7.6.4 Pile foundations

(1) The analysis of the external bearing capacity of piles shall be performed for all loads of the load cases 1, 2 and 3 (see Table 6.7.1, γ_F according to Table 4.3.3) in accordance with DIN 1054.

(2) The maximum static pile loads shall be determined.

(3) In the analysis of the external bearing capacity of the piles for tensile loading, the permanent actions shall be applied with a partial safety factor $\gamma_F = 1.0$, and the non-permanent actions with the partial safety factors according to Table 4.3.3. Verification shall be provided that the limiting condition against failure under tension is met for the above combination of actions and with $\gamma_P = 1.4$. For close spacing of the piles, the group effect of the piles shall be taken into account.

(4) Instead of a detailed analysis of fatigue with regard to the external load-bearing capacity, a substitute analysis may be provided to the effect that no tensile forces occur in the piles under the combinations of actions DLC 1.1 and 6.4 with a probability of exceedance of $p_f = 10^{-2}$ (equivalent to 1750 h in 20 years) with $\gamma_F = 1.0$.

Note:

Alternatively, the actions of DLC 1.1 and 6.4 which occur more than 10^4 times are recommended as a conservative approach.

(5) To sustain horizontal forces, also as a result of torsional loading, the piles should be inclined.

(6) For the external bearing capacity of piles under dynamic loading, it shall be taken into account by the soil expert that stronger requirements must be fulfilled in order to provide the same safety level as for piles under static loading.

Rules and Guidelines
IV Industrial Services

1 Guideline for the Certification of Wind Turbines

7 Machinery Components

Edition 2010

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Appendix 7.A

7.1 General

7.1.1 Assessment documents

(1) The following documents are required for assessment of the ultimate and serviceability limit states of machinery components of wind turbines.

(2) For the important components, parts lists are required with data about materials, data from the manufacturer in the case of mass-produced parts, data about the standard in the case of standardized parts etc.

(3) Engineering drawings (assembly drawings and individual-part drawings) of the important elements of the wind turbine, executed in standard form; clear identification shall be assured (parts designation, drawing number, modification index). They shall contain data about surface finish, heat treatment, corrosion protection etc.

(4) For mass-produced parts that have proved their suitability for use by successful service in comparable technical applications, type/data sheets are generally sufficient. However, further documentation/ verification may be necessary in individual cases for such parts. Main gearboxes do not count as mass-produced in this sense. The documentation required for this is set out in Section 7.4.

(5) Strength calculations for all components and means of connection shall verify the ultimate limit state and serviceability limit state totally, clearly and confirmably. The analyses shall be complete in themselves. They shall contain adequate data concerning:

- design loads
- static systems (analogous models)
- materials
- permissible stresses
- references used

Fatigue analyses shall be carried out in accordance with Section 5.3 using the codes and technical literature listed there.

(6) From the technical and calculation viewpoint, the documentation of the computational analyses shall form a unified whole together with all other documents (drawings, specifications). Here it shall be observed that the references of the adjacent components and structural areas that are mentioned in the computational analyses shall be included in the documentation. The formal and content-related requirements for the documentation of computational analyses for the certification of wind turbine components are set out as described in Section 5.A.5, especially 5.A.5.2. The necessary scope may deviate from that described there.

(7) If the analysis concepts of different standards and guidelines are applied, these shall not be mixed.

(8) Operations associated with moving or transportation machinery components or parts thereof during the construction or installation may have decisive influence on the overall design. These operations concerning the integrity are therefore included in the design review (Design Assessment and IPE).

(9) All lubricants and hydraulic fluids shall be specified with the corresponding type sheets. Oil collecting trays for the possible spilling of operating media shall be provided in the wind turbine (hub and nacelle).

(10) The design of the cooling and heating systems for operation of the wind turbine shall be specified.

(11) The specifications (requirements) of the wind turbine manufacturer for the design of the machinery components shall be appended to the verifications.

7.1.2 Materials

Requirements, verification and inspection certification are laid down in Section 3.3. Additional data are to be found in the following sections of this Chapter.

7.2 Blade Pitching System

7.2.1 General

(1) This section applies to the blade pitching systems of wind turbines as described below. In the event of other designs, the wording shall apply with the necessary changes.

(2) In systems with rotary drives, the torque needed for the pitching of the rotor blades is applied by a pitch motor with the associated pitch gearbox. The torque is transmitted by the pitch teeth to the blade bearing fixed to the rotor blade.

(3) In systems with a blade pitching mechanism actuated e.g. by one or more hydraulic cylinders, the torque needed for the pitching of the rotor blades is applied by a hydraulic cylinder. The torque is transmitted by the piston rod directly or indirectly to a linking point fixed to the rotor blade.

7.2.2 Assessment documents

General information on the assessment documents to be submitted is given in Section 7.1.

a) For the components of the blade pitching system, type sheets, specifications and assembly drawings shall be submitted.

b) Assembly and sectional drawings, including the associated parts lists and if applicable individual-part drawings, shall be submitted together with a description explaining the functional principle of the blade pitching system.

c) The calculations for the verification of the components of the blade pitching system shall be presented (including input data for the calculation, and presentation of the results with the relevant safety margins).

d) For the evaluation of the pitch teeth, the individual-part drawing of the pitch pinion, the pitch pinion shaft and the blade bearing teeth are required for pitch systems with a pitch gearbox. Individual parts drawings of the planet carrier and the gearbox housing at the output are required for pitch systems with a pitch gearbox as per Section 7.2.4.1.

e) The analysis of

  - the pitch gearbox teeth
  - the blade bearing teeth
  - the load capacity considering the fatigue loads
  - static strength against tooth breakage and pitting
  - Fatigue strength and static strength for the output shaft of the pitch gearbox and for the connecting elements of a pitch system with a pitch gearbox shall meet the requirements within the documentation as per Section 7.2.4.1.

f) In the case of systems with a blade pitching mechanism, actuated e.g. by one or more hydraulic cylinders, dimensioned drawings shall be submitted in which the pitching mechanism is shown with various blade angle positions. At least the maximum and minimum positions, and the positions in which the greatest loads act on the blade pitching mechanism, shall be shown.

g) For the components of the blade pitching mechanism, actuated e.g. by one or more hydraulic cylinders, a fatigue strength analysis and a static strength analysis shall be assessed for all load-transmitting components and connecting elements.

7.2.3 Loads to be applied

(1) For the calculation of the loading of the blade pitching system, the design loads as per Chapter 4 shall be applied.

(2) The static and load-dependent bearing friction moments shall be taken into account.

(3) For the fatigue analysis, the load duration distributions (LDD) or the load spectra shall be used. A distinction shall be made between operation with and without blade pitching. Here additional inertial loads – resulting from the rotor rotation – and dynamic vibration-exciting loads shall also be considered.

(4) The static strength analysis – with and without blade pitching operation – shall be performed for the design loads of the dimensioning load case as per Chapter 4. If the maximum torque about the blade axis obtained from the dimensioning load case is exceeded by the application of the pitch motor brakes or limited by the hydraulic pressure, then the maximum torque generated by the pitch system shall be used for static strength analysis of the pitch system.

(5) The teeth of the blade bearings are predominantly stressed on a very small part of their circumference during operation. The maximum rotation angle between start and stop procedures is approx. 90°. Because of this, the number of load cycles used in the gear calculation shall be determined in an appropriate way or at least multiplied with a factor depending on the sector of teeth used.

(6) In systems with a rotary drive, an application factor of KA = 1.0 is used for the static and fatigue strength analysis.

7.2.4 Verification of the blade pitching system

7.2.4.1 Pitch gearbox

(1) In case of pitch systems with a pitch gearbox, the gear load capacity calculation of the pitch gearbox and pitch teeth shall be based on ISO 6336:2006.

(2) The calculation of the load capacity from the fatigue loads shall be performed according to ISO 6336-6:2006 using the LDD or using an equivalent torque derived from the LDD according ISO 6336-6:2006, Annex A. The Palmgren-Miner sum used in the service life calculation shall be less than or equal to 1.

(3) Furthermore, an analysis of the static strength against tooth breakage and pitting in compliance with the safety factors according to Table 7.2.2 is also required.

(4) According to ISO 6336-5:2003, the predominant alternating load on the gears shall be considered. A reduction factor of 0.7 for the respective S/N curve shall be used. More favourable values may be used, e.g. based on ISO 6336-3:2006, Annex B.

Table 7.2.1 Safety factors for the fatigue strength analysis

Minimum safety for pitch gearbox and blade bearing teeth	Gearbox	Pitch teeth
Surface durability S_H	1.0	1.1
Tooth root breakage S_F	1.15	1.25

Table 7.2.2 Safety factors for the static strength analysis

Minimum safety for pitch gearbox and blade bearing teeth	Gearbox	Pitch teeth
Surface durability S_H	1.0	1.0
Tooth root breakage S_F	1.1	1.2

(5) For the output shaft of the pitch gearbox and for the connecting elements, a fatigue strength analysis and a static strength analysis shall be submitted. The analyses shall be performed in accordance with DIN 743, DIN 6892 and DIN 7190, or equivalent standards.

7.2.4.2 Connecting elements

Strength analyses for bolted connections are necessary wherever the bolts are essential to the transmission of loads (see Section 6.5).

7.2.4.3 Blade bearing

(1) With regard to the calculation and design of the blade bearing, reference is made to Section 7.3.

(2) The turbine manufacturer and/or the supplier of the blade bearing shall verify that the surrounding construction of the blade bearing is appropriate for the function of the blade bearing.

(3) The seals shall be protected in a way that they are not damaged by the prevailing environmental conditions.

Notes:

A single seal is not deemed to be adequate protection against external influences for the raceway of the blade bearing. The level of protection can be increased e.g. by a spinner or an additional seal.

It should be possible to exchange the seals of the blade bearing in the installed condition.

7.2.4.4 Lubrication system

(1) It shall be shown that an adequate film of lubricant is always provided on the flanks of the blade bearing teeth and also between the balls or rollers and the track surface of the blade bearing for all operational modes of the wind turbine.

(2) For the teeth of the blade bearing, a lubrication system is mandatory in general. The functionality of the lubrication system shall be documented (installation plan, lubrication intervals, lubricant distribution).

(3) If necessary, this requirement may be met by means of a test run e.g. taking place once within 24 h and during which the rotor blades and thus also the blade bearings are rotated by the maximum possible blade pitching angle.

(4) Appropriate collecting reservoirs should be provided to accommodate excess quantities of lubricant from the blade bearing teeth as well as from the blade bearing.

7.2.4.5 Additional verifications

(1) In the case of systems with electrical drives, the following Sections shall be applied: 8.2.3, 8.4.7, 7.2.4.5, para 4, 5, 6 and 7.

(2) For the verification of the hydraulic system, Section 7.9 shall be considered.

(3) If other systems than described in Section 7.2.1, para 2 or 7.2.1, para 3 are applied for blade pitching, the verification process of that systems shall be agreed with GL.

(4) The basis for thermal rating of an electrical drive shall be the most severe torque-time simulation run with the highest-torque rms value. The averaging time shall be 600 seconds, or the overall time of the simulation run to be used. This simulation run and the information about which load case was used shall be submitted to GL for assessment.

(5) The thermal rating of an electrical drive shall be determined by using IEC 61800-6 or IEC 60034-1. The rating calculation shall be submitted for GL assessment.

(6) The parameters to be set in the power semiconductor converter shall limit the operational range of the drive to the design values concerning thermal, mechanical and electrical capacity. A corresponding description shall be submitted for GL assessment.

(7) The design values of an electrical drive shall be provided for the full operational range of speed and torque, e.g. as figures for the following cases:

(i) as set by the control parameters

(ii) for all operational modes used (in the case of the field weakening range, the maximum speed shall be given additionally)

(iii) emergency braking run, e.g. by back-up power supply in the case of worst environmental conditions and lowest possible charging status

(iv) emergency braking run, e.g. by back-up power supply in the case of optimum environmental conditions and maximum possible charging status

Note:

According to section 4.5.4.3, para 3 the blade pitching system may be applied for testing of the Load Relevant control and safety system Functions (LRF).

7.3 Bearings

7.3.1 General

The guidelines of this section apply to roller bearings intended as rotor, gearbox or generator bearings in the drive train of a wind turbine, as blade or yaw bearings, and as bearings for other load-transmitting components. The requirements for plain bearings shall be determined for each individual case in consultation with GL.

7.3.2 Assessment documents

The following assessment documents shall be submitted for the bearings listed in Section 7.3.1:

a) assembly drawings of relevant application

b) calculation documents

c) relevant detail drawings, including number of rolling elements and geometry of the rolling elements and raceways (as listed in ISO 281:2007) if the bearings are not of a standard type

d) data sheet of lubricant, including necessary oil flow or necessary amount of grease

For each bearing in the drive train and for blade and yaw bearings, the bearing manufacturer shall be named clearly. If a bearing is supplied by two or more bearing manufacturers, the assessment documents shall be provided for each bearing manufacturer.

7.3.3 Materials

7.3.3.1 Approved materials

The scope of material tests (insofar as the bearings are of a standard type) shall be determined in consultation with GL.

7.3.3.2 Assessment of materials

(1) The scope of the material tests (insofar as the bearings are not of a standard type) shall be determined in consultation with GL and with due consideration of Section 3.3.1.2.

(2) The verifications of the bearing materials for the blade and yaw bearings shall be provided as per Section 3.3.1.2. For these bearings, which are predominantly loaded by small back-and-forth motions, the following shall be fulfilled:

- The notched-bar impact work in the case of the ISO-V test shall have a 3-test mean value ≥ 27 Joule at -20 °C; the lowest individual value shall be more than 70 % of the mean value. Deviation from these values is possible after discussion with GL if a lower stress level can be proved or on the basis of test results.
- The minimum hardness of the bearing raceway surfaces is 55 HRC.

7.3.4 Loads to be applied

(1) For the static rating, the extreme load (positive and negative) shall be used. Blade and yaw bearings are designed for a certain static load-bearing capacity. For the static load-bearing capacity, the extreme load shall be used according to Section 7.2.3 and 7.8.3.

(2) For the dynamic rating (determination of the rating life and determination of the contact stress), the equivalent operating load shall be used. Using a duration counting method, the representative loads for the calculation of the rating life and the contact stress shall be determined from the time series of the fatigue loads as per Chapter 4 (see also Section 4.B.2.3, para 9). With this counting method, the sum of revolutions n_i of the bearing is determined, during which the equivalent dynamic bearing load P_i acts within the individual class limits.

(3) For the analysis of the basic rating life and the modified rating life according to ISO 281:2007, the equivalent bearing load averaged over the lifetime can be calculated as follows:

$$P = \sqrt[p]{\frac{\sum P_i^p n_i}{N}} \quad (7.3.1)$$

where:

P_i = equivalent dynamic bearing load

p = 10/3 for roller bearings; 3 for ball bearings

n_i = number of revolutions during which Pi acts

N = total number of revolutions for the design lifetime of the wind turbine

(4) Alternatively, the dynamic rating can be calculated using the time series of the fatigue loads (normal operating load conditions) as per Chapter 4 and Appendix 4.B.

(5) Using a duration counting algorithm, the representative load levels and load cycles shall be derived and used as input to derive, for each load bin i, the sum of the revolutions n_i for which each bearing is loaded with an equivalent dynamic bearing load P_i. Both P_i and n_i are used to compute, for each load bin and each bearing, the corresponding dynamic life rating. The raceway contact stress shall be calculated for a Miner's sum equivalent from the derived duration load set (P_i,n_i).

(6) The operating loads on generator bearings and on gearbox output shaft bearings shall be superposed by the calculated reaction forces from the maximum permissible dynamic misalignment between the generator and gearbox.

(7) The extreme loads on generator bearings and on gearbox output shaft bearings shall be superposed by the calculated reaction forces from the maximum permissible static misalignment between the generator and gearbox.

7.3.5 Calculations

7.3.5.1 Static rating under extreme load

(1) For bearings used in the drive train, a static rating according to ISO 76:2006 shall be submitted. The static safety factor S_0 shall be at least 2.0.

(2) For blade and yaw bearings, which are predominantly loaded by small back-and forth-motions, the static rating is derived directly from the calculated maximum contact stress between rolling elements and raceway. The maximum permissible Hertzian contact stress shall be defined by the bearing manufacturer with consideration for the material, surface hardness and hardening depth, and shall be documented in the design calculation. A proof against core crushing has to be supplied for the yaw and pitch bearing raceways.

(3) The static safety factor is the ratio between the maximum permissible Hertzian contact stress and the maximum contact stress, and shall be at least 1.1.

(4) For the bearings in the actuators of pitch and yaw systems, the static safety factor S_0 according to ISO 76:2006 shall be at least 1.1.

(5) For all other bearings, the static safety factor shall be defined in consultation with GL.

7.3.5.2 Rating life

(1) For bearings used in the drive train, the following analyses shall be submitted:

- basic rating life calculation (L_{10}) according to ISO 281:2007
- modified rating life calculation (L_{10m}) according to ISO 281:2007
- modified reference rating life calculation (L_{10mr}) according to ISO/TS 16281:2008. Alternatively, the proprietary calculation methods developed by some bearing manufacturers can be used.

(2) For blade and yaw bearings, the rating life calculation is not necessary.

(3) For all other bearings, the basic or modified rating life calculation according to ISO 281:2007 can be performed after consultation with GL.

7.3.5.3 Contact stress

(1) For bearings used in the drive train, the contact stress shall be calculated taking into account the internal load distribution.

(2) The contact stress using the Miner's sum dynamic equivalent bearing load should not exceed the values listed in Table 7.3.1.

Table 7.3.1 Guide values for maximum contact stress at Miner's sum dynamic equivalent bearing load

Bearing position	**Maximum contact stress p_{max} in N/mm^2**
High-speed shaft	1.300
Intermediate shafts	1.650
Planets	1.500
Low-speed shaft	1.650
- The guide values apply for bearings manufactured from contemporary, commonly used, high-quality hardened bearing steel, in accordance with good manufacturing practice and basically of conventional design as regards the shape of rolling contact surfaces. - Values in this table are valid for a design lifetime of 20 years and shall be adjusted for designs with different design lifetime.	

7.3.5.4 Boundary conditions

(1) In the calculation of the modified rating life according to ISO 281:2007 and the modified reference rating life according to ISO/TS 16281:2008, the probability of failure shall be set to 10 %. The life modification factor a_{ISO} shall be limited to 3.8.

(2) The calculated modified rating life according to ISO 281:2007 may not be less than 130,000 hours. The calculated modified reference rating life according to ISO/TS 16281:2008 shall not be less than 175,000 hours or the operating life of the wind turbine.

(3) The following input parameters required for the modified rating life according to ISO 281:2007 shall be set out in the calculation:

- bearing temperature
- type of lubricant (oil, grease, additives etc.)
- lubricant viscosity at operating temperature
- operating lubricant cleanliness according to ISO 4406:1999

(4) The modified reference rating life calculation according to ISO/TS 16281:2008 shall consider at least the following effects in addition to the loads:

- internal design of bearings
- operating internal clearance
- deformation of bearings and shafts
- load sharing between rolling elements
- load distribution along roller length, considering actual roller and raceway profiles
- bearing temperature
- type of lubricant (oil, grease, additives etc.)
- lubricant viscosity at operating temperature
- operating lubricant cleanliness according to ISO 4406:1999

(5) The calculation of the modified reference rating life according to ISO/TS 16281:2008 shall be performed for each load level of the load duration distribution or for the equivalent load. A reduction of the specified spectrum to 10 load levels in accordance with Miner's Rule is permissible to minimize the computing effort. The life exponent for reducing the number of load levels shall correspond to the exponent used in the bearing calculation.

The combined modified rating life according to ISO/TS 16281:2008 for the corresponding bearing is then obtained as:

$$L_{10mr} = \frac{\sum q_i}{\sum \frac{q_i}{L_{10mr\,i}}} \qquad (7.3.2)$$

where:

L_{10mr} = combined modified rating life of the bearing

q_i = time share on the i-th load level

$L_{10mr\,i}$ = modified rating life of the bearing on the i-th load level

(6) The modified rating life calculation according to ISO 281:2007 as well as the modified reference rating life calculation according to ISO/TS 16281:2008 shall be based on an oil cleanliness class of -/17/14 according to ISO 4406:1999 for filtered systems. For unfiltered systems, a cleanliness class of -/21/18 shall be assumed.

(7) If the bearings of the plant are easily exchangeable on site and the corresponding bearing replacement intervals are specified, a shorter rating life may be permissible independently of the calculation method, after consultation with GL.

7.3.5.5 Minimum loading

Compliance with the minimum load shall be agreed between the component manufacturer and the bearing supplier in accordance with the general structural and operational conditions.

7.3.6 Miscellaneous

(1) On principle, the oils and greases recommended by the wind turbine manufacturer shall be used, whereby these shall comply with the prescribed component manufacturer's specification.

(2) During assembly, the bearing manufacturer's instructions shall be observed. The transport of bearings shall be undertaken in such a way that damage to rolling elements and raceways is prevented.

(3) The bearing shall be sealed if this ensures its function or protects the function of adjoining components.

(4) Owing to the special operating conditions for wind turbines, it should be possible to exchange generator bearings on the plant itself.

7.4 Gearboxes

7.4.1 General

The requirements in this section apply to gearboxes intended for installation in the drive train of wind turbines.

7.4.2 Assessment documents

(1) Assembly and sectional drawings of the gearbox, drawings of the housing, part drawings of all torque- and load-transmitting components plus parts list with data on materials shall be submitted for the assessment.

(2) The individual part drawings of the gears shall contain at least the data as per Table 7.4.2; otherwise this table shall be completed and appended to the assessment documents for each mesh. If the profile modifications cannot be obtained from the original drawings, these values shall also be given in tabular form for each gear. Data tables with data not listed in the part drawings shall include the number, revision status and date of issue of the part drawing.

(3) Strength analyses shall be provided for all torque- and load-transmitting components. Deformation shall be considered for those parts which influence the size and position of the gear contact patterns and bearing alignments. Verification of the adequate dimensioning of bearings and of any bolted connections that play a significant part in the transmission of loads shall be provided.

(4) Also required are specifications for the lubricant used and admissible temperature ranges, instructions for envisaged maintenance work and intervals, plus information about the monitoring appliances and auxiliary units (oil cooler, oil pump, oil filter etc.) installed. A specification of the corrosion protection provided shall be included. Furthermore, the gearbox specification of the wind turbine as well as the operating and maintenance manual (see Section 7.4.11) shall be appended.

7.4.3 Materials

7.4.3.1 Approved gear materials

All gears shall be made of materials complying at least material quality MQ according to ISO 6336-5:2003 (see also Section 3.3).

7.4.3.2 Approved shaft materials

(1) Pinion shafts shall be manufactured from hardened and tempered alloy steels according to the requirements of ISO 683-11. The shafts shall be stress-relieved after heat treatment.

(2) Materials for the shafts shall fulfil the strength requirements according to Section 7.4.6.1 and the quality requirements according to Section 7.4.3.3.

7.4.3.3 Assessment materials

(1) All torque-transmitting components of the gearbox shall be tested in accordance with the GL Rules for materials or equivalent standards. Appropriate verification according to EN 10204:2005 shall be provided for the materials. The material test documents (statements of compliance) as per Section 3.3.1.2 shall be available at the manufacturer and shall be submitted on request.

(2) The tests laid down in the regulations for materials may be curtailed with the consent of GL, if execution of the prescribed tests is not practicable because of the small size or particular manufacturing processes of individual components. For such components, GL shall be provided with quality verification in some other way.

7.4.4 Loads to be applied

7.4.4.1 General

(1) The load-transmitting parts of the gearbox are statically and dynamically loaded by the rotor torque. The dynamic portion depends on the characteristics of the driving side (rotor) and the driven side (generator, oil pump) and also on the masses, stiffnesses and damping values in the driving and driven portions (shafts and couplings) and the external operating conditions imposed on the wind turbine. Depending on the drive train concept of the wind turbine, additional loads in the form of forces and bending moments may be introduced at the gearbox input shaft and the gearbox output shaft, and these shall be taken into account.

(2) The fatigue and extreme loads shall comply with at least the requirements set out in Chapter 4.

7.4.4.2 Fatigue loads

(1) Using the time series of the fatigue loads (e.g. torque), the load duration distribution (LDD) shall be determined for the calculation of gears, bearings, shafts etc. These specify the sums of the times during which the torque remains within the defined class limits.

(2) In the LDD, all operating conditions described in Section 4.B.2.3, para 9 shall be considered for the determination of the fatigue loads to be applied. The torque levels shall have a clear relation to the rotational speed. Additional loads, e.g. through deformations, alignment errors and asymmetrical arrangements of the mechanical brakes, shall also be taken into account if applicable. Planet carrier(s) and gearbox housing (torque arm) shall be verified according to Section 5.3.

7.4.4.3 Extreme load

The maximum loads occurring in the drive train of the wind turbine as per Chapter 4 shall be used.

7.4.4.4 Scuffing load

The decisive load for the scuffing calculation is the highest torque of the LDD described in Section 7.4.4.2.

7.4.5 Calculation of load capacity of gears

7.4.5.1 General

(1) For torque-transmitting gears, a service life calculation according to ISO 6336-6:2006 (pitting, tooth breakage) using the LDD or a load capacity calculation using an equivalent torque derived from the LDD according to ISO 6336-6:2006 Annex A shall be submitted. The Palmgren-Miner's sum used in the service life calculation shall be less or equal to 1. The endurance limits for the gear materials shall comply with ISO 6336-5:2003. Sufficient load capacity shall be verified for all meshes in the main gearbox of the wind turbine. The required minimum safety factors are listed in Table 7.4.1.

(2) For torque-transmitting gears, a static strength analysis according to ISO 6336-2/3:2006 (pitting, tooth breakage) shall be submitted. Sufficient load capacity shall be verified for all meshes in the main gearbox of the wind turbine. The required minimum safety factors are listed in Table 7.4.1.

(3) A scuffing analysis according to DIN 3990-4:1987 or ISO/TR 13989:2000 shall be submitted. This analysis shall cover calculations according to the flash temperature method and according to the integral temperature method. The scuffing capacity of the oil shall be determined by the scuffing test FZG A/8.3/90 according to ISO 14635-1:2000. If the scuffing temperature is determined from FZG tests, one stage lower than the fail load stage shall be used for the scuffing analysis. Sufficient load capacity shall be verified for all meshes in the main gearbox of the wind turbine. The required minimum safety factors are listed in Table 7.4.1.

(4) A micropitting analysis according to ISO/TR 15144-1:2010 using the design load shall be submitted. Sufficient load capacity shall be verified for all meshes in the main gearbox of the wind turbine. The required minimum safety factor is listed in Table 7.4.1.

(5) A load distribution analysis (contact analysis) shall be submitted. The load distribution shall be verified by numerical evaluation with an advanced contact analysis that allows analysis of the load distribution in the helix direction and profile direction simultaneously, providing full information of the local loading in the entire contact area.

(6) Additionally, maximum operating loads and tolerance combinations in accordance with ISO 6336-1:2006 shall be checked with their resulting contact stress. Special care shall be taken to avoid stress raisers at the extremities of the contact area.

Table 7.4.1 Minimum safety factors

	Safety factor for pitting S_H	**Safety factor for tooth breakage S_F**	**Safety factors for scuffing S_B and S_{intS}**	**Safety factor for micropitting S_A**
Rated load (LDD)	1.2	1.5	-	1.2
Extreme load	1.0	1.4	-	-
Highest torque from LDD	-	-	1.5	-

7.4.5.2 Influence factors for the load capacity calculations

7.4.5.2.1 Application factor K_A

(1) The application factor K_A accounts for loads, additional to nominal loads, which are imposed on the gears from external sources.

(2) For a service life calculation according to ISO 6336-6:2006 using the LDD (see Section 7.4.4.2), K_A equals 1.0.

(3) For a load capacity calculation using an equivalent torque, the application factor K_A shall be determined according to ISO 6336-6:2006 Annex A from the LDD for each mesh.

(4) The static strength analysis for the gears shall be carried out using the extreme load and $K_A = 1.0$.

7.4.5.2.2 Dynamic factor K_v

(1) The dynamic factor K_v accounts for internal dynamic loads.

(2) The dynamic factor K_v shall be calculated according to ISO 6336-1:2006 Method B. Without a detailed dynamic analysis, $K_v < 1.05$ is not permissible.

7.4.5.2.3 Load distribution factor K_γ

(1) The load distribution factor K_γ accounts for deviations in load distribution e.g. in gearboxes with dual or multiple load distributions or in the case of planetary stages with more than two planet wheels.

(2) For planetary stages, the values given in Table 7.4.3 apply in relation to the number of planet wheels:

(3) If lower values than those given in Table 7.4.3 are used in analyses, they shall be verified by measurements with strain gauges applied beyond the active profile in the tooth root after consultation with GL. Calculations can be accepted, as long as the underlying model has been verified by measurements.

Table 7.4.3 Load distribution factor K_γ

Number of planet wheels	**3**	**4**	**5**	**6**	**7**
K_γ	1.0	1.25	1.35	1.43	1.5

Table 7.4.2 List of input data for gear rating

Gearbox						Certification No.			
Manufacturer					Stage				
Wind turbine					Gear stage	☐	Planetary stage		☐
Rated power	P			kW	No. of planets				
Rated speed	n			1/min	Load distribution factor	K_γ			
Application factor	K_A			-	Dynamic factor	K_V			-
Face load factors	$K_{H\beta}$			-	Transverse load factors	$K_{H\alpha}$			-
	$K_{F\beta}$			-		$K_{F\alpha}$			-
Geometrical data		Pinion	Wheel		**Tool data**		Pinion	Wheel	
Number of teeth	z			-					-
Normal module	m_n			mm	Coefficient of tool tip radius	ρ_{a0}^*			-
Normal press. angle	α_n			°	Coefficient of tool addendum	h_{a0}^*			-
Centre distance	a			mm	Coefficient of tool dedendum	h_{fP0}^*			-
Profile shift coeff.	x			-					
Helix angle	β			°	Protuberance	pr			mm
Face width	b			mm	Protuberance angle	α_{pr}			°
Tip diameter	d_a			mm	Machining allowance	q			mm
Root diameter	d_f			mm	Utilized dedendum coefficient of tool	h_{FfP0}^*			-
Lubrication data					Tool offset	B_{z0}			mm
Kin. viscosity 40 °C	ν_{40}			mm²/s	**Accuracy**				
Kin. viscosity 100 °C	ν_{100}			mm²/s	Accuracy acc. to ISO	Q			-
Oil temperature	δ_{Oil}			°C	Accuracy/tolerance sequence				
FZG load stage				-	Mean peak to valley roughness of flank	Ra_H			µm
Material data					Mean peak to valley roughness of root	Ra_F			µm
Material type					Initial equivalent misalignment	$F_{\beta x}$			µm
Endurance limit for contact stress	σ_{Hlim}			N/mm²	Normal pitch error	f_{pe}			µm
Endurance limit for bending stress	σ_{Flim}			N/mm²	Profile form error	f_f			µm
Surface hardness				HV	Date:				
Core hardness				HV					
Heat treatment method				-	Signature:				

7.4.5.2.4 Face load factors $K_{Hß}$, $K_{Fß}$ and $K_{Bß}$

(1) The face load factors account for the effects of non-uniform load distribution over the gear face width.

(2) The face load factors shall be determined by sophisticated calculation models as described in ISO 6336-1:2006 annex E. These models shall at least take into account:

- gear accuracy and tooth modifications
- alignment of axes
- elastic deformation and deflections of gears, shafts, bearings, housing and foundation
- bearing clearances

(3) $K_{Hß} < 1.15$ is not permissible.

(4) Comparison of the calculated load distribution with the real contact pattern during prototype testing is mandatory. For planetary stages, this comparison can only be done by strain gauge measurements or similar. A further comparison after a reasonable period of operation in the wind turbine is recommended.

7.4.5.2.5 Transverse load factors $K_{H\alpha}$, $K_{F\alpha}$ and $K_{B\alpha}$

(1) The transverse load factors take into account the non-uniform distribution of transverse load between several pairs of simultaneously contacting gear teeth.

(2) For gears with an accuracy as required in Section 7.4.5.3, para 1, the transverse load factors can be set to unity.

7.4.5.2.6 Life factors

The life factors Z_{NT} according to ISO 6336-2:2006 and Y_{NT} according to ISO 6336-3:2006 shall be set to 0.85 at $N_L = 10^{10}$.

7.4.5.3 Design requirements

(1) Gear accuracy as per ISO 1328-1:1995 shall comply with at least accuracy grade 6 for surface-hardened external and internal gears and at least accuracy grade 8 for through-hardened internal gears.

(2) For ground external and internal gears, the maximum arithmetic surface roughness shall be $Ra \leq 0.8$ µm. The maximum arithmetic surface roughness for through-hardened internal gears shall be $Ra \leq 1.6$ µm.

(3) The design load for the involute profile and helix modifications should correspond to that load level of the LDD that contributes most to surface durability.

(4) Integer ratio designs, e.g. $z1/z2 = 21/63$, are not allowed.

(5) GL reserves the right to call for proof of the accuracy of the gear-cutting / gear-grinding machines used and for testing of the procedure used to harden the gear teeth.

7.4.6 Strength analysis for shafts and connecting elements

7.4.6.1 General

(1) Fatigue and static analyses (general stress analyses) shall be carried out for all shafts. For connecting elements (e.g. keys, slip joints, press fits), only a static analysis is required.

(2) The analyses shall be performed for shafts in accordance with DIN 743:2005, for keys in accordance with DIN 6892:1998 and for press fits in accordance with DIN 7190:2001, or equivalent codes.

7.4.6.2 Analysis of the fatigue strength

(1) If a representative load spectrum is available, a fatigue analysis shall be carried out. Further notes for the fatigue analysis are given in Section 5.3.3.

(2) The fatigue analysis may also be carried out in a simplified form using fatigue limits as per DIN 743:2005. Here rated loads shall be used for computation, with consideration of the application factor determined for the gear calculation. The theoretical safety factor S shall then in each case be equal to or greater than the minimum safety factor $S_{min} = 1.2$. The theoretical safety factor is determined with consideration of bending, tension/compression and torsion, assuming phase balance.

7.4.6.3 Analysis of the static strength

(1) The analysis of the static strength against forced rupture shall be based on the load case in Chapter 4 that produces the highest load on the component.

(2) The component loads shall have a partial safety factor $\gamma_M \geq 1.1$ relative to the yield point of the material.

7.4.7 Additional verifications

7.4.7.1 Gearbox bearings

For the design, calculations, assessment documentation and e.g. oil filtration details to be submitted for gearbox shaft bearings, refer to Section 7.3.

7.4.7.2 Bolted connections

Strength analyses are required for bolted connections playing a significant part in the transmission of loads (see Section 6.5 “Bolted connections”).

7.4.7.3 Housing, torque arm and planet carrier

Regarding the gearbox housing, torque arm and planet carrier, fatigue strength analyses and/or deformation analyses shall be performed, insofar as these parts play a significant part in the transmission of power (e.g. introduction of rotor blade loads into the housing, in the case of a hub affixed directly to the gearbox input shaft). General requirements for strength analyses are stated in Section 5.3. The influence of deformations of these components on the meshes and the bearings shall be taken into account. If applicable, deformations determined by computation shall be taken into account for the calculation of the mesh and the bearings.

7.4.7.4 Analysis of the cooling system

A heat balance for the gearbox shall be submitted for verification of the thermodynamics of the design. Sufficient cooling of the gearbox shall be proved in this balance.

7.4.8 Equipment

(1) For checking the oil level, a mechanical arrangement (e.g. oil level gauge, oil dip-stick) shall be provided. The temperature shall be monitored. For gearboxes with pressure lubrication, the oil pressure shall be monitored after the cooler and before entry into the gearbox. Adequate lubrication of all teeth and bearings shall be ensured in every operating state of the wind turbine. For operation at low temperatures, a heating system shall be provided.

(2) An oil filtering system shall be provided to meet the requirements for the rating life of the gearbox bearings. Flanged oil pumps shall be mounted accessibly at the gearbox and shall be exchangeable.

(3) The sealings for the gearbox shall be suited to the operating conditions of the wind turbine and the installation position of the gearbox. Verification shall be provided of the compatibility of the gaskets with the gearbox oil used.

(4) The housing of the main gearbox in wind turbines shall be provided with removable inspection hole covers, so that it is possible to check the teeth of all meshes, for gears in planetary stages at least by the use of an endoscope.

7.4.9 Inspection of gearboxes

(1) Gearboxes for wind turbines shall be inspected in the manufacturer’s works. The final inspection of the series-produced gearboxes shall take place after a test run under partial load lasting several hours. The detailed test plan (also regarding noise assessment) shall be agreed by the gearbox manufacturer and the wind turbine manufacturer.

(2) Newly developed main gearboxes for wind turbines shall be subjected to a prototype test at a suitable test bench and also in operation on a wind turbine (see Sections 1.2.2.4.3, 10.1.2 and 1.2.2.7). The precise procedure for the tests of gearboxes for wind turbines is described in Section 10.7.

(3) Following a successful prototype test, the tests of identical series-produced gearboxes can be reduced to testing for sufficient production quality.

(4) The detailed scope of the prototype test shall be specified in consultation with GL before the test commences. The reduced extent of series testing shall be defined in the documentation of the prototype test.

7.4.10 Running-in

(1) For the gearboxes in wind turbines, a running-in period after commissioning shall be defined in consultation with the gearbox manufacturer. During this period, the power output by the rotor shall be limited in the control system. If no malfunctions are detected, the gearbox load can be increased to full load after several hours and with constant checking. During the running-in period, the oil and bearing temperatures (planet bearings not mandatory) shall be monitored and the lubrication system shall be kept in constant operation.

(2) Furthermore, after a prolonged outage, the output shall be limited with due regard for the oil sump temperature (see also Section 2.3.2.17). Because the transmitted power through the gearbox influences the oil temperature, the limitations specified by the gearbox manufacturer have to be followed.

7.4.11 Manuals

The gearbox manufacturer shall define together with the wind turbine manufacturer in a written manual the relevant maintenance, monitoring and precautionary measures for erection, transport and operation of the gearboxes, with a view to ensuring that the design lifetime of the gearbox is reached. According to Section 7.4.2, the manual forms part of the assessment documents for the certification of wind turbine gearboxes and shall contain binding statements on at least the following points:

- characteristic values and properties of permissible lubricants
- intervals required for oil analyses (also for oil purity) and oil changes
- required maintenance and inspection intervals, as well as a description of the measurements to be performed in each case. These shall be incorporated into the maintenance manual of the wind turbine as per Section 9.4.
- operating parameters to be logged, and the corresponding limiting values
- notes on the proper assembly of the gearbox
- notes on the transport by sea, air or land (rail or road), both as separate component and within the nacelle of the wind turbine
- notes on the storage of the gearbox over periods exceeding half a year

7.5 Mechanical Brakes and Locking Devices

7.5.1 Brakes

7.5.1.1 General

The following applies to the mechanical brakes of the rotor and the yaw system.

7.5.1.2 Assessment documents

a) general arrangement and installation drawings, single-part drawings of all force-transmitting parts, circuit diagrams of the hydraulic, pneumatic and electrical equipment including a parts list

b) data sheet of the brake, stating the operational conditions (permissible pressure/current/ voltage, permissible temperatures)

c) data sheet of the lining, stating the material, friction coefficient (static and dynamic), permissible temperatures and wear characteristics, data regarding the material combination of lining and brake drum/disc

d) verifications as given in Section 7.5.1.4

7.5.1.3 Materials

Reference is made to Section 3.3.

7.5.1.4 Verifications

7.5.1.4.1 Rotor brake

(1) The mechanical brake is important in order to bring the rotor to a standstill (see Section 2.2.3.4.1, para 3).

(2) Due to the heat generated and the wear arising from continuous operation of mechanical brakes, it is not possible just to limit the rotational speed of the rotor with these brakes. Therefore the brakes shall be designed such that they are capable of bringing the rotor to a standstill.

(3) For the torques in the drive train that are relevant for the design of the mechanical brake, the following terms apply (see Fig. 7.5.1):

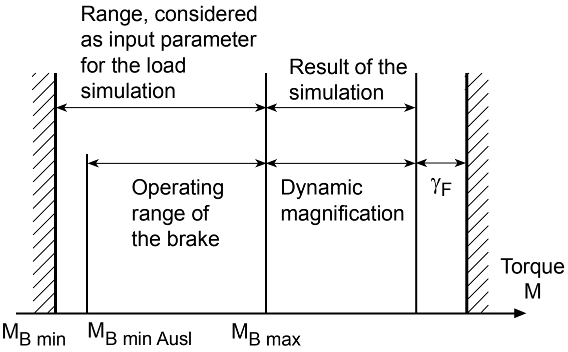

Fig. 7.5.1 Sketch of the relevant torques in the drive train

(4) The minimum required braking moment M_{Bmin} and the maximum braking moment M_{Bmax} are input parameters for the load simulations of the wind turbine as per Section 4.3.3.

(5) A calculation of the minimum and maximum braking moment ($M_{BminAusl}/M_{Bmax}$) shall be carried out, taking into account the variation of brake pressure, friction coefficient, warming and wear of the lining.

(6) During the braking process, a moment is produced in the drive train which exceeds the maximum braking moment by the dynamic magnification. The magnification is obtained by the load simulation as described in Section 4.3. It has to be shown that the magnified maximum braking moment times the safety margin γ_F does not damage the structure of the turbine (see Section 4.3 for γ_F). This is the limiting condition of the maximum braking moment M_{Bmax}.

(7) The minimum required braking moment M_{Bmin} has to be such that the rotor is brought to standstill (see Section 7.5.1.4.1, para 2). This is analysed by the load simulation as described in Section 4.3.

(8) It shall be shown that $M_{BminAusl}$ is at least 1.1 times bigger than M_{Bmin}. This is the limiting condition of the minimum braking moment $MB_{minAusl}$.

(9) For all force- or moment-transmitting components and joints, a general strength analysis shall be carried out, using the maximum force that the brake can achieve.

(10) The analysis shall include the brake caliper support and the drum/disc.

(11) The general strength analysis is described in Chapter 5.

(12) It shall be shown that the permissible temperatures are not exceeded during the braking process. The proof shall be provided with the least favourable braking moment.

(13) Automatic monitoring of the brake may be necessary; see Section 2.3.2.11.

(14) Additional proofs may be required in individual cases (e.g. spring calculations for spring-actuated brakes).

7.5.1.4.2 Yaw brake

(1) A calculation of the minimum and maximum braking moment shall be carried out, taking into account the variation of brake pressure, friction coefficient, warming and wear of the lining.

(2) The minimum and maximum braking moment shall be in accordance with the requirements of the control system.

(3) For all force- or moment-transmitting components and joints, a general strength analysis shall be carried out, using the maximum force that the brake can achieve.

(4) The analysis shall include the brake support and the drum/disc.

(5) The general strength analysis is described in Chapter 5.

7.5.1.5 Miscellaneous

(1) The brake surfaces shall be protected against undesirable influences (e.g. lubricants) by means of covers, splashguards or suchlike.

(2) The brake shall be capable of holding the rotor or nacelle even if there is no power supply. The period of time for which the grid failure shall be assumed is specified in Section 2.2.2.13.

(3) According to section 4.5.4.3, para 3 the mechanical brake may be applied for testing of the Load Relevant control and safety system Functions (LRF).

7.5.2 Locking devices

7.5.2.1 General

The following applies to the locking devices of the pitch system, the rotor and the yaw system. Section 2.3.3 has to be observed.

7.5.2.2 Assessment documents

a) general arrangement and installation drawings, single-part drawings of all force-transmitting parts, circuit diagrams of the hydraulic, pneumatic and electrical equipment, including a parts list

b) verifications as given in Section 7.5.2.4

7.5.2.3 Materials

Reference is made to Section 3.3.

7.5.2.4 Verifications

(1) The locking devices shall be capable of holding the rotor blade, the rotor or the nacelle against

- a gust during erection or maintenance (Section 4.3.3, DLC 8.1) and

- an annual gust (Section 4.3.3, DLC 8.2)

(2) A general strength analysis using these forces and moments shall be carried out for all force- and moment-transmitting parts of the locking devices.

(3) The general strength analysis is described in Section 5.

(4) The locking bolt shall be verified regarding the shear, bending and surface pressure.

(5) If necessary, the locking disc shall be verified against buckling.

(6) When using two or more locking devices simultaneously, the distribution of the moment on the individual devices shall be calculated.

(7) The function of the locking devices shall be described in the maintenance instructions.

(8) The following applies to the locking devices of the pitch and yaw system only:

(9) The locking device need not necessarily be located permanently at the pitch or yaw system; it may also be an external lock which is mounted whenever required.

(10) The yaw locking device can also be provided by two independent brake systems.

7.6 Couplings

7.6.1 General

The following applies to couplings in the drive train.

7.6.2 Assessment documents

a) assembly and individual-part drawings of all torque-transmitting components,

b) parts lists with data on materials,

c) documents as per DIN 740 Part 1, 1986, Section 4.12,

d) a record (by way of example) of the function test performed on a slipping coupling (if present),

e) verifications as given in Section 7.6.4

7.6.3 Materials

Reference is made to Section 3.3 (Materials).

7.6.4 Verifications

(1) For all torque-transmitting components, a general strength analysis, a fatigue analysis and an analysis on stress through periodic torque fluctuations shall be submitted. Here the axial, radial and angular misalignment shall be taken into account.

(2) In the general strength analysis, the maximum moment resulting from the design loads as per Chapter 4 shall be used as the basis.

(3) Continuous transmission of that maximum moment is not necessary, but the loading caused by its occurrence shall not result in damage to the coupling. If a reduction in that maximum value is achieved by design measures (e.g. a slipping coupling), the reduced value may be used for the coupling design. Here the tolerance of the slipping moment shall be considered.

(4) The general strength analysis is described in Chapter 5.

(5) The fatigue verification may be carried out by component testing under conditions resembling operation or by computational analyses.

(6) For computational analysis, the fatigue loads as per Chapter 4 shall be used as a basis. The calculation shall be performed in accordance with Chapter 5.

(7) If it is to be expected that excitation by the rotor or the driven machine can cause alternating torques when passing through a resonance range or when operated at the rated speed, it shall be verified that the coupling is not damaged by these torques.

(8) The constancy of the slipping torque over the lifetime or until the next maintenance shall be proven for each limiter design. The results can be transferred to limiters with other sizes but with the same design.

(9) The balance quality has to be agreed upon between the wind turbine manufacturer and the coupling manufacturer.

(10) If rubber elements are used, these shall be verified in accordance with Section 7.7.

(11) The temperature influence of a brake disc (if present) on non-metallic coupling components shall be considered (e.g. fire hazard, damage to the rubber elements of the coupling).

(12) In individual cases, it may be necessary for an expert from GL to inspect a coupling from series production.

7.7 Elastomer Bearings

7.7.1 General

The following applies to elastomer bearings which are important for the structural integrity of the turbine, whose failure presents a high potential danger for human health and life, or whose failure results in a severe consequential damage with a long-term breakdown of the turbine.

7.7.2 Assessment documents

a) single-part drawing of the elastomer bearing

b) load-deformation diagram for main loading directions

c) type sheet of the elastomer with the following statements:

  - shore hardness, density, elongation at tear, modulus of shear, permissible static deformation
  - permissible operating conditions (chemical resistance, operating temperatures)
  - creep properties of the elastomer bearings (see also design lifetime of the wind turbine, Section 4.2.2)

d) verifications as given in Section 7.7.4

7.7.3 Loads to be applied

For the calculation of the loading of the elastomer bearings, the design loads as per Chapter 4 shall be applied.

7.7.4 Verifications

(1) It shall be shown that the elastomer bearings provide adequate safety against the extreme and fatigue loads

(2) The safety factors of Section 5.3.2.1 and Section 5.3.3.2.2, Table 5.3.1, have to be observed.

(3) Elastomer bearings shall preferably be subjected to compressive and/or shear loading.

(4) If the extreme and fatigue load analyses are carried out with the aid of test results, the test procedure and the results derived from the tests shall be presented in a plausible manner.

(5) When transferring test results to the actual application, the assumed reduction factors shall be documented.

(6) In the selection of the elastomer bearings, the environmental conditions (e.g. temperature, humidity, ozone) at their place of installation within the wind turbine shall be taken into account. Rarely occurring conditions shall be observed as well.

(7) The effects on the spring characteristic – up to the typical loading of the elastomer bearing and for the temperature range from -20 °C to +50 °C (but at least for -20 °C, +20 °C and +50 °C) or for the extreme temperatures to be expected at the place of installation for the elastomer bearing within the wind turbine – shall be described.

(8) If contamination with aggressive media can be expected during normal operation, it has to be proven that the bearing can safely resist such an exposure for a period not less than the minimum maintenance period.

Note:

For the determination of the lifetime of the elastomer, no generally valid computation standard is currently available, since the dynamic characteristics of the elastomer usually depend strongly on

- *the frequency,*
- *the environmental conditions,*
- *the load amplitudes,*
- *the mean load, and*
- *the relationship between surface area and volume.*

For this reason, it will often be necessary to make use of test results when performing the analysis.

7.7.5 Miscellaneous

(1) Due to the dynamic loading of the elastomer bearings, an annual inspection is necessary as a rule (e.g. visual inspection). Thus possibilities for inspecting, and if necessary exchanging, the elastomer bearing easily shall be provided.

(2) For the metallic parts and the bolted joints of the bearings, the requirements of Section 5.3 and 6.5 have to be observed.

(3) It shall be noted that, due to dynamic loading, the internal temperature of the elastomer bearings can exceed the ambient temperature at the place of the installation, thereby possibly exceeding the permissible operating temperature of the elastomer bearings.

7.8 Yaw System

7.8.1 General

(1) This section applies to the yaw system of wind turbines as described below. In the event of other designs, the wording shall apply with the necessary changes.

(2) The design of the yaw system shall be verified for proper function in accordance with the system concept.

(3) The torque necessary to make the nacelle track the wind is provided by a yaw motor with the associated yaw gearbox (rotary drive). The torque is transmitted by the yaw teeth from the yaw pinion to the yaw bearing.

(4) The nacelle is supported on the tower head either by a friction yaw bearing or by a roller yaw bearing. The rotating of the nacelle around the tower axis is usually braked either by a brake in the yaw motor and/or by yaw brakes acting on a brake disc fixed to the tower head or the nacelle.

(5) To exclude damages caused by alternating stresses at the yaw teeth due to oscillating motions around the tower axis, a constantly acting residual brake torque should be applied, either by the innate and load-dependent friction torque of the yaw bearing or by an additional yaw brake system.

7.8.2 Assessment documents

(1) General information on the assessment documents to be submitted is given in Section 7.1.

(2) For the components of the yaw system, type sheets, specifications and assembly drawings shall be submitted.

(3) Assembly and sectional drawings, including the associated parts lists and if applicable individual-part drawings, shall be submitted together with a description explaining the functional principle of the yaw system.

(4) The calculations (including input data for the calculation, presentation of the results with the relevant safety margins) for the verification of the components of the yaw system shall be presented.

(5) For the evaluation of the yaw teeth, the individual-part drawings of the yaw pinion shaft and the yaw bearing teeth are required, as well as individual-part drawings of the planet carrier and the gearbox housing at the output of the yaw gearbox.

(6) The analysis of

- the yaw gearbox teeth
- the yaw bearing teeth
- the load capacity considering the fatigue loads
- the static strength against tooth breakage and pitting
- fatigue and static strength analysis for the output shaft of the yaw gearbox and for the connecting elements

of a yaw system with a yaw gearbox shall meet the requirements posed within the documentation as per Section 7.8.4.1.

7.8.3 Loads to be applied

(1) For the calculation of the loading of the yaw system, the design loads as per Chapter 4 shall be applied.

(2) For the fatigue strength analysis of the yaw gears, the load duration distributions (LDD) and the load spectra shall be used. A distinction shall be made between operation with and without yawing. For operation with yawing, innate and load-dependent yaw bearing friction torque as well as gyroscopic torque of the rotor at rated yaw and rotor speed shall be considered in the fatigue strength analysis (see Section 4.3.4.1, para 10.

(3) The static strength analysis – with and without operation of the yaw system – shall be performed for the design loads of the dimensioning load case as per Chapter 4. If applicable, the following additional dimensioning loads shall be considered:

- the maximum torque of the yaw motor brakes for the static strength analysis of the yaw gearbox, the yaw bearing teeth and the connecting elements according to Section 7.8.4.2

- If yaw motors are directly switched to the grid without application of soft-start switches or frequency converters, the static strength analysis for the teeth and the shaft connections of the yaw gearbox shall be performed by applying three times the rated yaw motor torque. The occurrence of peak torques at three times the rated motor torque in direct-switched yaw motors shall be considered also in the fatigue strength analysis of the gears and their shaft connections.

(4) For the static strength analysis, an application factor of $K_A = 1.0$ is used.

(5) When determining the number of load cycles or the load duration per tooth occurring during yawing, the specifications in Section 4.3.3.1 shall be used as a basis. Operation of the yaw system shall be considered to occur during 10 % of the turbine's service life.

7.8.4 Verification of the yaw system

7.8.4.1 Yaw gearbox

(1) The gear load capacity calculation of the yaw gearbox and yaw teeth shall be based on ISO 6336:2006.

(2) The calculation of the load capacity from the fatigue loads shall be performed according to ISO 6336-6:2006 using the LDD or using an equivalent torque derived from the LDD according to ISO 6336-6:2006, Annex A. The Palmgren-Miner sum used in the service life calculation shall be less than or equal to 1.

(3) Furthermore, an analysis of the fatigue and static strength against tooth breakage and pitting in compliance with the safety factors according to Table 7.8.1 and Table 7.8.2 is also required.

(4) According to ISO 6336-5:2003, the predominant alternating load on the gears shall be considered. A reduction factor of 0.7 for the respective S/N curve shall be used. More favourable values may be used, e.g. based on ISO 6336-3:2006, Annex B.

Table 7.8.1 Safety factors for the fatigue strength analysis

Minimum safety for yaw gearbox and yaw bearing teeth	Gearbox	Yaw teeth
Surface durability S_H	1.0	1.1
Tooth root breakage S_F	1.15	1.25

Table 7.8.2 Safety factors for the static strength analysis

Minimum safety for yaw gearbox and yaw bearing teeth	Gearbox	Yaw teeth
Surface durability S_H	1.0	1.1
Tooth root breakage S_F	1.1	1.2

(5) For the output shaft of the yaw gearbox and for the connecting elements, a fatigue strength analysis and a static strength analysis shall be submitted. The analyses shall be performed in accordance with DIN 743, DIN 6892 and DIN 7190, or equivalent codes.

(6) Strength analyses for yaw gearbox housings and planet carriers may be necessary (see Section 7.1.1.4).

7.8.4.2 Connecting elements

Strength analyses for bolted connections are necessary wherever the bolts are essential to the distribution of forces (see Section 6.5).

7.8.4.3 Yaw bearing

(1) For the calculation and design of the yaw bearing, reference is made to Section 7.3.

(2) The turbine manufacturer and/or the supplier of the blade bearing shall verify that the surrounding construction of the yaw bearing is adequate for the function of the yaw bearing.

(3) The seals shall be so protected that they are not damaged by the prevailing environmental conditions.

Note:

It should be possible to exchange the seal of the yaw bearing in the installed condition.

7.8.4.4 Lubrication system

(1) It shall be shown that an adequate film of lubricant is always provided on the flanks of the yaw bearing teeth and also between the balls or rollers and the track surface of the yaw bearing for all operational modes of the wind turbine.

(2) For the teeth of the yaw bearing, a lubrication system is mandatory in general. The functionality of the lubrication system shall be documented (installation plan, lubrication intervals, lubricant distribution).

(3) Appropriate collecting reservoirs should be provided to accommodate excess quantities of lubricant from the yaw teeth as well as from the yaw bearing.

7.8.4.5 Yaw brake

(1) Notes on the calculation of brakes are given in Section 7.5.

(2) If a permanent application of a braking moment is required according to the system concept, the function of the brakes shall also be ensured in the event of failure of the power supply.

7.8.4.6 Additional verifications

(1) In the case of systems with electrical actuating yaw motors, Chapter 8 shall also be considered.

(2) For the verification of the hydraulic system, Section 7.9 shall be considered.

Note:

According to section 4.5.4.3, para 3 the yaw system may be applied for testing of the Load Relevant control and safety system Functions (LRF).

7.9 Hydraulic Systems

7.9.1 General

(1) The guidelines in this Section apply to hydraulic systems necessary for operation (e.g. yaw motion and rotor blade pitch control) or forming part of a braking system (e.g. blade pitch adjustment in fault situations and rotor brakes).

(2) In addition to the statements made here, national requirements may also have to be observed Assessment documents

The following assessment documentation is required:

a) hydraulic functional diagram in standard form (e.g. as per ISO 1219-2) with associated parts list

b) electrical circuit diagrams showing the actuation of the hydraulic system valves, insofar as electro-hydraulic control and regulation is planned

c) data sheet of the safety-related components

d) calculations and data for the actuators (e.g. piston diameter, moments acting on servomotors, design of articulated joints and levers), accumulators, pipelines, hoses and valves (e.g. flow rates and reaction times)

e) data concerning pump unit design (storage volume, limitation of pressure, fluid level check etc.)

f) data on the execution of filters

g) details on the service life of the component used (e.g. hoses, accumulators), if these are shorter than the design lifetime of the wind turbine (see Section 4.2.2)

7.9.2 Materials

(1) In the selection of materials for the force-transmitting components, it shall taken into account that they are possibly subjected to dynamic loading.

(2) Seamless or longitudinally welded steel pipe shall be used for piping. Suitable high-pressure hoses in accordance international codes shall be used as flexible pipe connections.

(3) All components not made of corrosion-proof materials shall be provided with a corrosion protection system.

7.9.3 Design and construction

The following points shall be taken into account:

(1) The design and construction of hydraulic systems shall be in accordance with recognized rules (see e.g. ISO 4413, DIN EN 982).

(2) Adequate dimensioning of the components (e.g. pumps, piping, valves, actuators, accumulators) to guarantee the desired reaction times, actuation speeds and actuating forces.

(3) During operation, pressure fluctuations can arise in hydraulic components which can cause fatigue damage.

(4) A clear separation is required for the components and assemblies of the independent braking systems (see Section 2.2.3.4).

(5) The hydraulic system should be so designed that the wind turbine is in a safe condition in case of no pressure or of failure of the hydraulics.

(6) In the event that hydraulic actuators (e.g. rotor brake or blade pitching system), fulfil their safety function only if there is hydraulic pressure, the hydraulic system shall be so designed that the wind turbine can be kept in a safe condition following failure of the power supply to the pump or the valves. The duration of this failure shall be assumed identical to the duration of the grid failure specified as a fault condition in Section 2.2.2.13, para 3.

(7) The weather conditions under which the installation is intended to operate (oil/fluid viscosity; possible cooling, heating etc.) (see Section 4.2) shall be taken into account.

(8) Leakage shall not impair the system’s ability to function. If leakage occurs, this shall be recognized and the wind turbine shall be controlled accordingly.

(9) Actuators shall always be “hydraulically loaded” if they are hydraulically moved in two directions.

(10) In the layout of piping, it shall be taken into account that components may move relative to one another and thereby dynamically stress the pipes.

(11) All components shall be protected in a suitable manner against accidental loads not considered in the dimensioning (e.g. weight of a person on pipes).

(12) Adequately large oil troughs shall be provided to ensure that hydraulic fluid does not pollute the environment in the event of leakage in the hydraulic system, but runs into the collecting troughs instead.

(13) Hydraulic accumulators fixed to the hub shall be suitable for the special requirements resulting from the rotating movements of the hub.

7.10 Drive Train Dynamics

7.10.1 General

7.10.1.1 Scope

(1) This section applies to the dynamic analysis of wind turbine drive trains. The purpose of the analysis is the investigation of load-increasing resonances in the main drive train components using a detailed simulation model of the drive train. These resonance phenomena are usually not included in the global simulation model used for the determination of the design loads.

(2) When determining the design loads (see Section 4.3.4.1), the dynamic behaviour of the drive train shall be considered in a suitable manner. For this, the drive train is modelled in an idealized form within the load simulation through a system comprising of few rotating masses and torsional springs. The reduction of the complex drive train system and the determination of the values of torsional springs, rotating masses, and possibly damping values shall be presented during the assessment of drive train dynamics.

7.10.1.2 Implementation

(1) The drive train is reckoned as all torque-transmitting components from the rotor to the generator including the elastic mounting of the drive train. The wind field and the wind turbine's control and electrical system are not part of the investigation.

(2) The dynamic behaviour of the drive train depends mainly on the mass, inertia and stiffness properties of the drive train components. Varying drive train configurations might cause variations of these properties. Hence, a new analysis of the drive train dynamics is necessary if different types of the following components are installed in the same type of wind turbine:

- rotor blades
- main shaft
- gearbox
- elastic gearbox and generator supports
- generator coupling
- generator
- type of main or gearbox bearings

(3) A sensitivity analysis can be carried out in order to identify the contribution of individual components to the overall dynamic behaviour of the drive train. As a result, it might be possible to reduce the number of combinations to be investigated by separate analyses of the drive train dynamics.

(4) Results of the analysis are Campbell diagrams showing eigenfrequencies related to excitations. The investigation of the eigenfrequencies shall include an analysis of the energy distribution for each mode shape. In the case that the evaluation of these results shows potential resonances, more detailed investigations shall be carried out in the time domain. The increase of the local loads to individual parts shall be evaluated regarding the load-carrying capacity.

(5) The assumptions for the design load simulation model shall be compared to the results obtained by means of the detailed model of the drive train.

7.10.2 Method of analysis

(1) For the analysis of the dynamic drive train behaviour, numerical simulation procedures shall be applied (e.g. multi-body approaches). The analysis shall be carried out in the frequency and/or time domain.

(2) For the assessment of resonance frequencies, a modal analysis is mandatory. The analysis requires a linearized model for determining eigenfrequencies and mode shapes. In the case of non-linear simulation models, an adequate number of linearization states shall be considered.

(3) Torsional, axial and bending modes shall be considered. A model with only torsional degrees of freedom can be used if the calculation results are validated by measurement. The measurements can be carried out during prototype testing on the gearbox test bench. For details, see Appendix 7.A.

(4) For the evaluation of resonances, the excitations have to be considered.

(5) For the detailed evaluation of potential resonances, the distribution of energies needs to be analysed for each mode shape. Other means of analysis shall be agreed with GL.

(6) The analysis shall cover the operating range of the wind turbine from n_1 to n_3 (see Section 2.2.2.6).

(7) For the detailed investigation of potential resonances, the simulation of a run-up shall be carried out in the time domain (see Section 7.A.2.3).

(8) Further recommendations and requirements regarding modelling aspects are given in Appendix 7.A “Drive Train Dynamics”.

7.10.3 Documentation

(1) The configuration of the analysed drive train shall be documented by a listing of wind turbine type, grid frequency and type information for all major components as well as relevant drawing numbers.

(2) Stiffness, mass, inertia and damping values of all drive train components shall be documented.

(3) Eigenfrequencies and relevant excitation frequencies shall be presented. A detailed listing of excitation frequencies that need to be considered is given in Appendix 7.A “Drive Train Dynamics”.

(4) The results of modal analysis and the excitation frequencies shall be combined in Campbell diagrams. Furthermore, mode shapes and energy distributions need to be illustrated.

(5) The assumptions for parameterization of the drive train model for global load assumptions shall be compared to the results obtained from the detailed model of the drive train.

(6) A detailed interpretation of the documented results shall be carried out in terms of an in-depth evaluation of potential resonances.

Appendix 7.A Drive Train Dynamics

7.A.1 General

Requirements and recommendations regarding the definition of objective, type and scope required for the analysis of drive train dynamics as well as modelling aspects and details on documentation are given in the following. The necessary extent of analysis and modelling detail level depends on the particular project and can vary from the requirements defined here.

7.A.1.1 Scope

(1) The objective of this Appendix is to provide information and instructions on the dynamic analysis of wind turbine drive trains using numerical simulation procedures such as multibody systems.

(2) The aim is to provide support for the selection of the appropriate method, in the modelling and performing of the analysis, and in the interpretation of the results. The Appendix is to be considered as an application-related supplement to the general requirements formulated in this Guideline (see Section 7.10).

(3) The following refers primarily to conventional drive train designs using a gearbox to increase the rotational rotor speed. For drive trains using a slow speed generator or other methods of power transmission, the statements shall apply with the necessary adaptations. In general, the analysis consists of the following steps:

- simplification of the complex drive train into an equivalent model
- determination of the required input for stiffness, mass, inertia and damping values
- set-up of the simulation model
- execution of the analysis
- verification of the model
- evaluation, assessment and documentation of the results

7.A.2 Modelling of the system

The technical data from the component manufacturers shall be used to build the simulation model.

7.A.2.1 Discretization of the model

(1) The simulation model shall include all major drive train components. The individual component is subdivided into segments represented by rigid bodies. Gears and bearings can be modelled as single bodies, whereas for shafts and rotor blades finer discretizations are recommended. Interaction between the bodies is modelled by force elements (e.g. spring/damper elements). For shafts and complex parts, the use of elastic bodies is recommended. Table 7.A.1 lists the major drive train components which shall be considered at least.

(2) All relevant eigenfrequencies of the drive train shall be considered. Thus, all relevant mechanical properties (mass, inertia, stiffness) shall be included in the model.

(3) The discretization of the major drive train components shall be attuned to the shape of the respective component. Moreover, it shall be selected in a way that allows identifying all eigenfrequencies of the component at or below the second harmonic of the highest excitation frequency. The discretizations given in Table 7.A.1 should be taken as a guide.

Table 7.A.1 Major drive train components and requirements for modelling

Major drive train components	Minimum requirements for modelling structure of components	Minimum requirements for modelling degrees of freedom of components
Rotor blades	Minimum three bodies per blade; elastic recommended	Edgewise and flapwise
Hub	Rigid body	Torsional, axial, bending
Main shaft	Minimum two rigid bodies; elastic recommended	Torsional, axial, bending
Low-speed shaft coupling	Rigid body	Torsional, axial, bending
Gearbox housing	Rigid body; elastic recommended	Torsional, axial, bending
Planet carrier	Rigid body; elastic recommended	Torsional, axial, bending
Gearbox shafts	Minimum three rigid bodies, elastic recommended	Torsional, axial, bending
Gearbox gears	Rigid bodies	Torsional, axial, bending
Elastic gearbox support	Connecting spring-damper element	Translational
Brake disc	Rigid body	Torsional, axial, bending
Generator coupling	Minimum three rigid bodies; elastic recommended	Torsional, axial, bending
Generator rotor	Rigid body	Torsional, axial, bending
Generator housing	Rigid body	Torsional, translational
Elastic generator support	Spring-damper element	Translational
Main frame	Rigid body; elastic recommended	In compliance with model of component
Bearings	Spring damper element	Full stiffness matrix recommended

(4) Depending on the excitation mechanisms, the extent regarding the number of DOFs (degrees of freedom) of each individual component shall be chosen adequately. Torsional, axial and bending DOFs shall be considered as a general rule.

(5) A model with torsional DOFs only can be used if the calculation results are validated by measurement (see Section 7.10.2).

(6) If elastic bodies are used for the modelling, the boundary conditions shall be consistent in both model domains (e.g. finite element method, multi-body system).

7.A.2.2 Model input parameters

(1) The model input data shall include the mass, inertia, stiffness and damping values of the components. The required input for masses and inertias can be derived from CAD data, by analytical calculation or by measurement. The elasticity of complex parts shall be determined by finite element analysis, by measurement or, in cases of simple geometries, by analytical formulae.

(2) For the gears, the meshing stiffness can be calculated on the basis of ISO 6336-1, Method B, or by measurement.

(3) Stiffness properties of bearings shall be provided by the bearing supplier. The behaviour should be represented using a full stiffness matrix. Besides the non-linear characteristics for the axial stiffness, coupling terms shall be considered.

(4) Damping properties shall be determined by measurements or, if applicable, data from the literature can be used. The final adjustment can be made by measurements on the actual drive train. Damping should only be applied to parts of the model where it will occur in wind turbines e.g. bearings, toothings.

(5) If the analysis is carried out in the time domain, sources of excitation due to variations in the component stiffness and component inertia values shall be considered. These are at least:

- blade passing
- variations in tooth meshing stiffness
- imbalance of major drive train components (rotor, brake disc, coupling, and rotor of generator)
- communication frequencies of controllers (e.g. pitch and yaw controller)

7.A.2.3 Boundary conditions

(1) The frequency range for analysis in the frequency domain shall be chosen wide enough to cover the excitation frequencies according to Table 7.A.2.

(2) The analysis range for the time domain simulation shall be chosen in accordance with the operating range of the wind turbine.

(3) The interaction of the mechanical and electrical part of the wind turbine shall be considered adequately, e.g. by applying the generator's speed-dependent torque characteristics or by implementing the wind turbine's controller algorithm.

(4) In order to impose all operating conditions on the drive train, the simulation of a run-up by steadily increasing the rotational speed is an appropriate procedure. The run-up can be carried out in the speed- or torque-driven mode (see Fig. 7.A.1).

7.A.2.4 Check of the model and input data

(1) The input data used for the modelling of the drive train shall be checked thoroughly for errors. The effectiveness of the data check can be increased appreciably by visualization of the data.

(2) The interconnection of components forming the assembled drive train model shall be reviewed by visual inspection of e.g. animations and by plausibility checks of the modal results. It has been found that the comparison of damped and undamped eigenfrequencies is an effective procedure for locating defects in the model.

(3) The simulation model should be adequately validated, e.g. by evaluating the results from gearbox test runs on a test bench, to ensure plausible behaviour in relation to the actual drive train.

7.A.2.5 Validation of the torsional model by measurement

(1) If a simulation model with only torsional degrees of freedom is used for the analysis, the calculation results shall be validated by measurement (see Section 7.10.2). This can be carried out at a gearbox test bench.

(2) The measurements shall show comparable results in terms of eigenfrequencies and torque characteristics.

(3) The test shall be carried out by a run-up of rotational speed, covering the operating range of the drive train (see Fig. 7.A.1).

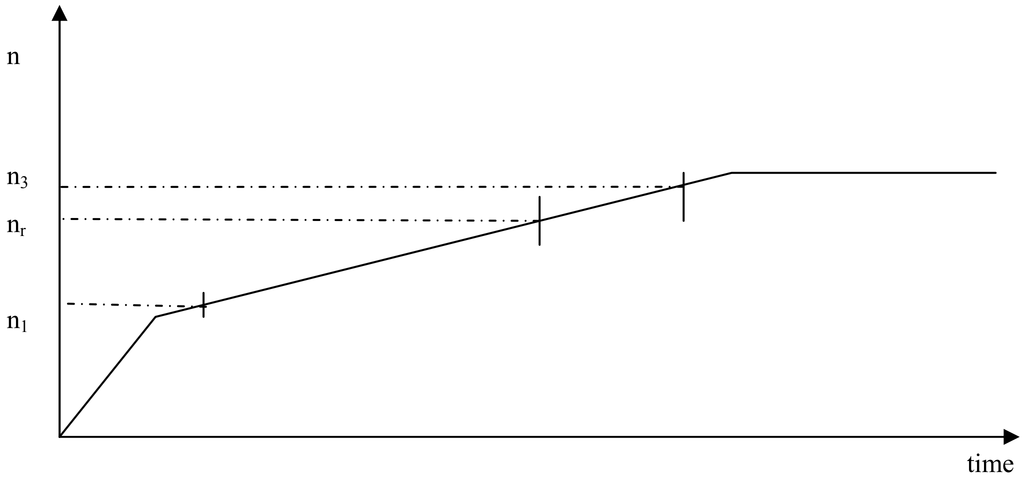

Fig. 7.A.1 Example for a synthetic run-up load case

(4) Required parameters to be measured are: torque and speed at the input and output shaft, structure-borne noise in three spatial directions at the torsion supports and at additional positions on the gearbox housing to obtain the relevant measured frequencies.

(5) The measurements shall show all frequencies up to at least 500 Hz.

(6) The presentation of the results shall be done by means of Campbell diagrams and waterfall plots of all stages of the gearbox, showing the interrelation of speed, frequency and intensity.

7.A.2.6 Verification of the global drive train parameters

(1) To verify the drive train model parameters used within the global load assumptions, the detailed drive train model shall be analysed in this regard. In most cases, these parameters are "resulting drive train stiffness" and "moment of inertia of generator rotor". The verification can also be performed by comparing the first eigenfrequency obtained from the detailed model of the drive train to the corresponding value derived from the global simulation model. The deviation may not exceed ±5 %.

(2) Depending on the model set-up and simulation possibilities, other assessment techniques are permitted, if plausible.

7.A.3 Calculation and evaluation of the results

(1) For the time domain calculation, the time range and sampling rate shall be chosen large enough so that, for each level of rotational speed, a steady state will be reached and reliable Fast Fourier Transform (FFT) with 2^n supporting points can be performed. n shall be chosen in such a way that an appropriate resolution will be obtained and that the necessary frequency range can be analysed.

(2) Calculated time series of e.g. rotor speed and torque and the load levels in all springs shall be checked with respect to the correct reproduction of e.g. transmission ratio, rotational direction, angular displacement of shafts etc.

(3) The results shall be checked for plausibility. This involves checking of eigenfrequencies and mode shapes to see whether their magnitude and shape, respectively, are credible in comparison to similar drive train layouts and to experience.

7.A.4 Extended evaluation

(1) In the event that the analysis shows abnormalities in terms of e.g. resonances that occur in the operating range of the wind turbine, extended evaluations become necessary. These can be performed by applying a more detailed simulation model (see Section 7.A.2.1) or by measurement on the actual drive train.

(2) It is recommended that the simulation model of the drive train be used to analyse transient dynamic loading caused by extreme load cases (e.g. DLC 1.4, DLC 1.5, DLC 2.2, DLC 9.2; see Chapter 4) that are relevant for the drive train.

7.A.5 Documentation

7.A.5.1 General

(1) The formal and content-related requirements relating to the documentation of the analyses of drive train dynamics for the certification of wind turbine machinery components are set out in the following. The necessary scope may deviate from that described here.

(2) The requirements for the documentation are to a large extent presented independently of the analysis approach (MBS, hybrid approaches etc.).

(3) From the technical and calculation viewpoint, the documentation of the computational analysis shall form a unified whole together with all other documents, such as component-related drawings, data sheets and wind turbine type information.

(4) The document shall have an unambiguous title designation with reference and revision number. The creation and release date shall be easily recognizable.

(5) The documentation shall be preceded by an overall table of contents reflecting the current state of revision in each case.

(6) The objective, the type (methods used and theories applied) as well as the extent of the calculation shall be indicated.

(7) Reference shall be made to the wind turbine type and configuration and the grid frequency. A listing of the type information for all major components and the relevant assembly and single-part drawings is required.

(8) Rotational operating speed ranges of the wind turbine defining the range for the analysis shall be documented according to Section 2.2.2.6

(9) The relevant frequencies should be named according to Table 7.A.2.

Table 7.A.2 Naming of frequencies

Frequency identification	Symbol	Orders that should be analysed
Eigenfrequencies	f_N1, f_N2, f_N3, …	-
Excitation frequencies (shafts)	f_E1, f_E2, f_E3, …	Rotor shaft: 1P, 2P, 3P, 6P Gearbox shafts: 1P, 2P
Excitation frequencies (gear meshes)	f_ZLSS_0, f_ZLSS_1, …, f_ZIMS_0, f_ZIMS_1, …, f_ZHSS_0, f_ZHSS_1, …	Fundamental frequency, 1st and 2nd harmonic

7.A.5.2 Documentation of input data

(1) The mass, stiffness and damping properties of all components that are considered in the drive train model shall be documented. Depending on the chosen simulation approach, not all of these data may be directly available. In this case, other forms of documentation shall be agreed with GL.

(2) Excitation frequencies and their harmonics originating from shafts and gear meshes shall be documented with reference to the rated speed of the wind turbine.

(3) The analogous model that represents the simplified drive train and serves as basis for the simulation model shall be demonstrated (see Fig. 7.A.2). The model shall include all major drive train components and their interconnections.

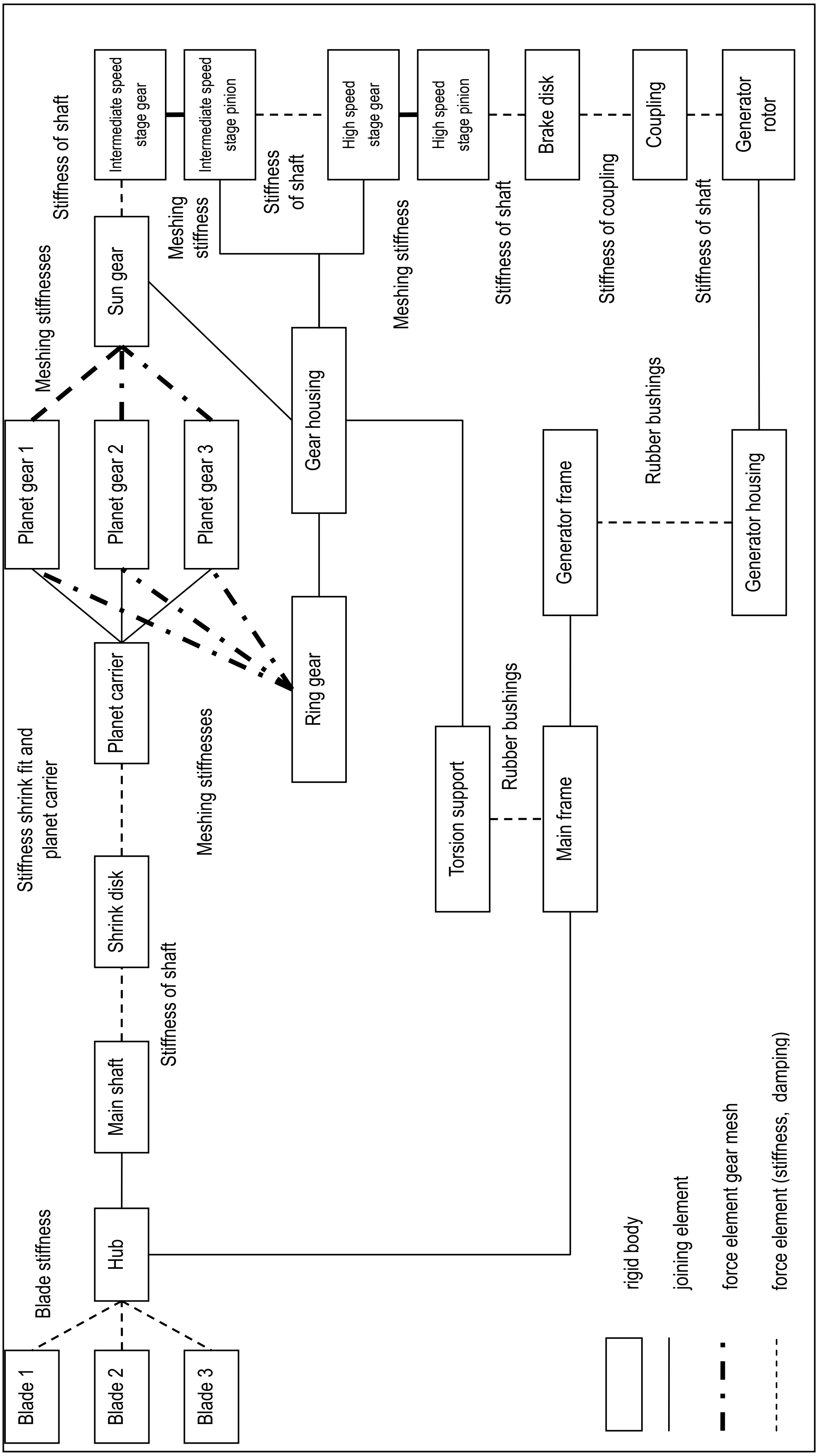

Fig. 7.A.2 Analogous model of a generic drive train (bearing force elements not shown)

7.A.5.4 Documentation of simulation environment and model

The following requirements shall be applied especially for the documentation of analyses applying multi-body, finite element or hybrid approaches. The documentation shall contain the following data:

- identification of the program used (name, variant and version designation; if applicable, designations of various software packages for pre-processing, post-processing and the solution phase)
- description of the degrees of freedom applied to the individual body
- description of the elements used (e.g. rigid body, type of beam element)
- properties of the interconnecting elements, such as joints, constraints, force elements
- description of the elements used to model the excitation mechanisms
- description of flexible bodies, the underlying finite element models and the modal reduction procedure (if applicable)
- solver settings of the individual multi-body system

7.A.5.5 Documentation of results

(1) Eigenfrequencies of the linearized system and excitation frequencies shall be documented in Campbell diagrams (see Fig. 7.A.3). The frequency range that needs to be analysed shall be chosen wide enough so that the excitation frequencies according to Table 7.A.2 are covered. The operating speed range and rated speed of the wind turbine shall be indicated in the diagram.

(2) In order to analyse the excitability of eigenfrequencies, mode shapes and energy distributions shall be taken into account in the analysis. Components/bodies with large portions of the total kinetic energy (> 20 %) shall be mentioned for each eigenfrequency.

(3) The identification of potential resonances by means of Campbell diagrams and energy distributions should be supplemented by frequency response calculations. Results should be documented in frequency response plots.

(4) Simulation results of a run-up shall be evaluated by Campbell diagrams depicting the amplitude as a function of frequency and excitation (e.g. rotational speed). Frequency and excitation should be displayed in two dimensions, and the amplitude as a colour spectrum. All stages of the drive train shall be analysed by these means.

(5) The “resulting drive train stiffness” calculated by using the detailed drive train model and the “moment of inertia of the generator” shall be compared to the parameters used within the global load assumptions. The verification can also be performed by comparing the first eigenfrequency derived from the detailed model of the drive train to the corresponding value derived from the global simulation model.

(6) A detailed interpretation of the documented results shall be carried out in terms of an in-depth evaluation of potential resonances.

7.A.5.6 Documentation of test bench measurements

For the documentation of the measurements during testing on the test bench, the following is required:

(1) A description of the test bench set-up with details regarding the motor, generator, coupling, and mounting of the gearbox on the test bench

(2) Range of rotational speed, and duration of the rpm sweep

(3) Description of the measurement equipment

(4) The results shall be presented by means of Campbell diagrams and waterfall plots, showing the interrelation of speed, frequency and intensity.

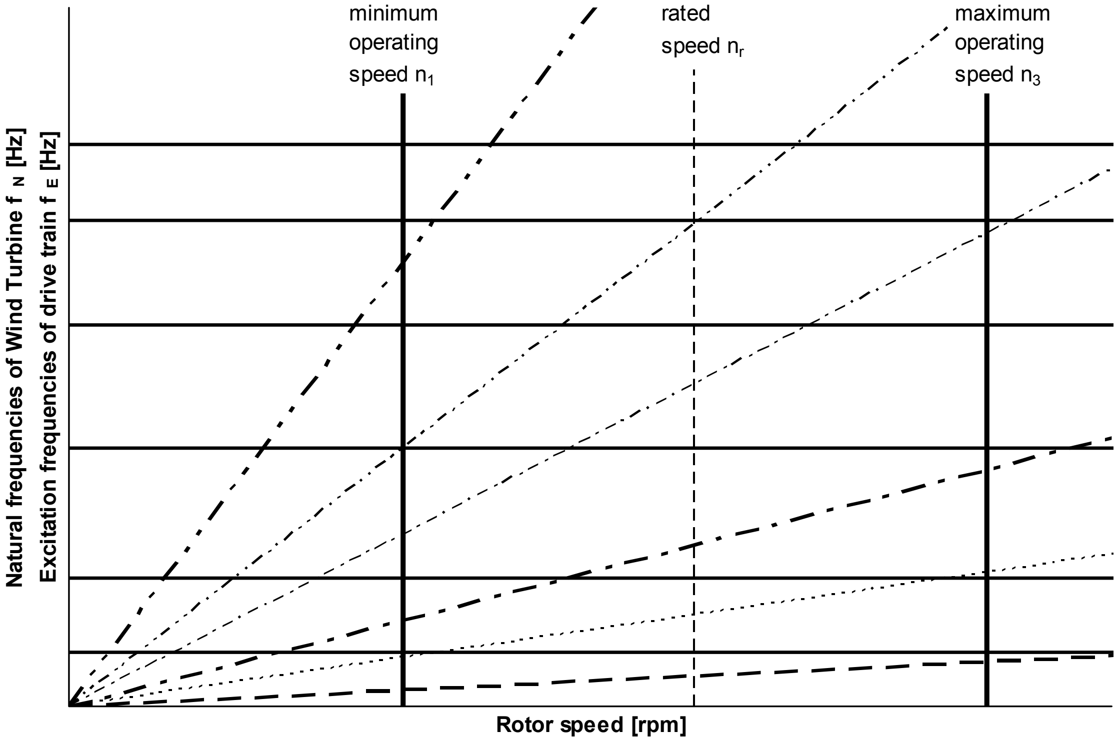

Fig. 7.A.3 Campbell diagram

Rules and Guidelines
IV Industrial Services

1 Guideline for the Certification of Wind Turbines

8 Electrical Installations

Edition 2010

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Appendix 8.A

8.1 Area of Application

8.1.1 Application

The provisions of this Chapter apply to installations for the conversion, generation and use, distribution and transmission of electric energy and to electrical and electronic control equipment in wind turbines, insofar as they are located within the wind turbine (tower / nacelle / hub) or form an integral part of the wind turbine.

8.1.2 Scope

Chapter 8 describes the requirements for components and systems related to

- rotating electrical machines
- power transformers
- frequency converters
- medium voltage switchgear
- back-up power supply systems
- low-voltage switchgear, controlgear and switchboards including safety-related parts according to Section 2.1.4
- cables, lines and accessories
- lightning protection

8.1.3 Standards

(1) All electrical equipment and individual components shall be designed in accordance with recognized standards, which shall be listed in the technical documentation.

(2) Special attention shall be paid to the protective measures, as listed in the IEC series 60364 "Electrical installations of buildings". The GL assessment is limited to those parts named in Chapter 8.7.

(3) IEC 60071 Insulation co-ordination shall be applied but will not be assessed by GL on a general level.

8.1.4 Operating and environmental conditions

(1) All electrical components shall be designed to comply with the operating and environmental conditions expected at the installation site.

(2) External environmental conditions are to be assumed as given according to Section 4.2.4. Internal temperature assumptions concerning locations with electrical installations (at least in the hub and at the frequency converter) are to be submitted for GL assessment, considering all three cases as follows for each place of installation.

- wind speed above rated wind for 8 hours at maximum outside temperature
- grid loss after more than 8 hours of operation at wind speeds with more than rated wind
- no wind for longer than 8 hours at the minimum outside temperature

8.1.5 Parallel operation with the grid

(1) With regard to the grid quality expected for wind turbines, assumptions made in Section 4.2.5 shall be used. They may be detailed by the manufacturer of the wind turbine when describing grid failure behaviour as required in Section 4.3.3.9, para 2.

(2) Wind turbines intended for parallel operation with the grid require approval from the relevant grid operator. Part of this can be the corresponding Grid Code Compliance Certification (GCC). In general, the Grid Code of the relevant grid operators shall be taken into account for this purpose. A list of Grid Codes can be found on the Internet at http://www.gl-group.com/pdf/IGCC_list.pdf.

(3) Some countries require Grid Code Compliance by law (e.g. Spain and Germany). Reference is made to Appendix 1.A1, para 2, concerning national requirements in Germany.

8.1.6 Stand-alone operation

(1) In the absence of specific data, the guideline values given in Table 8.1.1 shall be assumed for the operating conditions in stand-alone operation:

Table 8.1.1 Permissible voltage and frequency deviations in stand-alone operation

Parameter		Deviation	
		permanent	short-term
A	Frequency Voltage	± 5 % ± 10 %	± 10 % (5 s) ± 20 % (1.5 s)
B	Voltage	± 20 %	

A: General

B: Storage batteries and frequency converters

(2) For storage devices, Chapter 8.6 shall be applied as far as applicable.

Note:

Deviations from this Guideline are permissible if the connected consumers are suitable for this. For DC charging generators, the voltage conditions for battery-charging operation apply.

(3) It is strongly recommended that the load case DLC 9.2 be assumed, giving all details on different grid failure possibilities as symmetrical and unsymmetrical short circuit failures, frequency and voltage changes for both, wind change and load change cases.

(4) Measures for detection and control of the electrical grid frequency shall be implemented in isolated grids. These measures shall be in line with the assumptions made in Section 8.1.4, para 1 and 2.

(5) If further requirements are missing for the design, EN 50160 should be applied.

(6) As a proof of the ability to run in isolated grids, the wind turbine shall be operated for 100 hours during high and low winds with variable and changing loads. The test is accepted if no protection has tripped and the turbine has never transgressed the design values for grid frequency, voltage, power factor and current. Applicable parts of IEC 62124 may be used if helpful. A corresponding report with data on wind speed and load power shall be provided for GL assessment.

8.1.7 Assessment documents

The following documents are to be submitted for GL assessment. They are described in more detail in the corresponding chapters as given below.

8.1.7.1 General

a) temperature assumptions according to Section 8.1.4, para 2

b) electrical schematics and an overview diagram (formerly called “single line”) according to IEC 61082 which should include data as required in Section 2.1.2, para 1, item j, Sections 8.7.3.1 and 8.8.1, para 5

c) electrical overview diagram for the safety system with the SRP/CS (safety-related parts of control systems)

d) The following documentation is required for the assessment of electrical components:

  - general functional descriptions of and maintenance instructions for electrical appliances
  - SRP/CS: documentation necessary for the plausibility verification according to Section 8.7.7.
  - parts lists with the design data and manufacturer’s information for all important electrical appliances, including the sensors and limit switches used

8.1.7.2 Rotating electrical machines

a) corresponding marking plates for the corresponding machines (see Section 8.2.1, 8.2.3)

b) design data and calculations according to Section 7.2.4.5, para 4, 5 and 7 for electrical pitch, 8.2.2, para 9, 8.2.3, para 1, 8.2.6, para 1, 8.2.7, para 2 and voltage ratio between stator and rotor for generator

c) filter design and calculation documents according to Section 8.2.2, para 5

d) equivalent circuit diagram according to Section 8.2.2, para 7

e) measurement reports on tests, as defined in Section 8.2.8, 8.2.2, para 5 and 8.2.6, para 1

f) maintenance instructions

g) documents according to the given sections, if applicable, as given in Section 8.2.2, para 8

h) If draught-ventilated machines are used, documentation according to Section 8.2.5, para 2 shall be submitted for Design Assessment.

i) generator bearing documentation

  - static rating of generator bearings
  - modified rating life as per ISO 281
  - sectional drawings of the generator, indicating the installation position of the bearings and the rotor
  - sectional drawings of the generator rotor, indicating the shaft dimensions, centre of gravity and moment of inertia of the generator rotor

8.1.7.3 Power transformers

a) According Section 8.3.1, para 2 and 3, name plate data and type test records of the transformer as per IEC 60076-1 (2000-04) “Power transformers – Part 1: General” are to be provided. For dry-type power transformers, see Section 8.3.4.

b) description according to Section 8.3.1, para 5, 8.3.4, para 2 or para 4 and 8.3.5, para 1

c) design and commissioning documentation according to Section 8.3.2, para 2 and 3, Section 8.3.3, Section 8.3.4, para 3

8.1.7.4 Frequency converter

a) statements of the frequency converter manufacturer according to Section 8.4.1, para 4, Section 8.4.2, para 1, 4 through 6, 10 and 20, Section 8.4.7, para 2 and 4

b) material documentation according to Section 8.4.2, para 11

c) test reports according to Section 8.4.4, para 4 and Section 8.4.5

d) calculations or measurements according to Section 8.4.3, para 10

e) descriptions according to Section 8.4.1, para 4, Section 8.4.2, para 3, 13, 17 and 18, Section 8.4.3, para 6 and 11

f) manuals according to Section 8.4.6

g) documentation according to 7.2.4.5, para 6 if frequency converters are used within the blade pitching system

8.1.7.5 Medium-voltage switchgear

a) type test records according to Section 8.5.1, para 2

b) name plate data according to Section 8.5.1, para 3

c) drawings and commissioning manuals according to Section 8.5.3, para 4

8.1.7.6 Back-up power supply systems

a) descriptions according to Section 8.6.2 (charging equipment)

b) calculations according to Section 8.6.3, para 3 and 4

c) manuals according to Section 8.6.3, para 4

d) data sheet of the back-up power supply system

8.1.7.7 Low-voltage switchgear, controlgear and switchboards

a) Test reports according to IEC 60364-6 shall be submitted as required in Section 8.7.1, para 5 and according to IEC 60439-1 as required in Section 8.7.4.4.

b) calculations for bus bar strength according to Section 8.7.5.3

c) calculation of short-circuit current for the main power transmission circuit between generator and medium-voltage switchgear according to Section 8.7.2.2, para 3 and 4 (e.g. for generator stator, generator rotor, frequency converter, transformer, circuit breakers etc.)

d) list of switching devices according to Section 8.7.2.2, para 5

e) description of electric arc detection according to Section 8.7.2.2, para 6

f) additional documentation according to Section 8.7.7, para 3

8.1.7.8 Cables, lines and accessories

The documents according to Section 8.8.3 are to be submitted.

8.1.7.9 Lightning protection

8.1.7.9.1 General

a) descriptions or drawings concerning:

  - lightning protection zones and statement of the manufacturer according to Section 8.9.2.2, para 1
  - bonding bars and bonding conductors with their cross-sectional areas
  - the path lightning current will flow with the expected share of lightning current
  - details about the lightning protection of outside instrumentation
  - diagram showing the SPDs and protection levels achieved by their installation (single-line)
  - drawing of the earthing system even in the case when no foundation assessment is made

concerning civil engineering. The assessment of the foundation concerning structural integrity and civil engineering is highly recommended.

b) documents according to Section 8.9.2.1, para 2 if LPL < I

c) manufacturer's maintenance plan according to Section 8.9.3.9.1, para 6

8.1.7.9.2 Outer lightning protection

a) verification according to Section 8.9.3.1, para 1 and 9 (temperature rise), 8.9.3.5, para 2 (bearings) and 8.9.3.7, para 2

b) test reports of high-voltage and high-current testing according to Section 8.9.3.1, para 8 (e.g. if carbon fibre) and of mechanical rotor blade tests according to 8.9.3.1, para 2

c) description according to Section 8.9.3.9.3, para 6 (corrosion protection)

8.1.7.9.3 Inner lightning protection

a) data sheet for surge arresters according to Section 8.9.3.9.1, para 1

b) description according to Section 8.9.3.9.1, para 2 (SPD coordination)

8.2 Rotating Electrical Machines

8.2.1 General

(1) Electrical machines in wind turbines (generator, main auxiliary electrical motors) shall on principle comply with IEC 60034 "Rotating electrical machines". This shall be proven by corresponding statements of the electrical machine manufacturer on the rating plate.

(2) All data on the rating plate shall be provided as required in IEC 60034-1 subclause 10.2. A corresponding rating plate shall be placed at each electrical machine.

8.2.2 Rating of generators

(1) Generators for wind turbines shall be designed for continuous operation (duty type S1 as per IEC 60034-1). Other duty types shall be agreed upon with GL in advance.

(2) The power rating according to the generator rating plate may differ from the total wind turbine rated power P_r as defined in Section 2.2.2.7, para 1. This is acceptable, as long as the test reports of the generator tests show compliance with duty type S1 and insulation class as designed, as well as capacity of the generator to operate at P_r.

(3) The speed rating of the generator shall take into account the frequency converter rating. The frequency converter system voltage and the level of the corresponding voltage testing depend on the maximum speed n_{max}, too. See Section 8.4.2, para 7 for details.

(4) The insulation system of the generator (e.g. rotor, bearings) must support voltage peaks. The maximum voltage change rate (dU/dt) shall be in compliance with the maximum value generated by the frequency converter system.

(5) If the generator is used with frequency converter system, some method shall be deployed to limit the bearing current and shaft voltage. This will come in the form of a combination of grounding system, converter filters and bearing insulation. Corresponding calculations and measurements of the shaft current and voltage shall be submitted for assessment (see Section 8.4.2, para 18 and Section 8.4.5 para 7). The calculations shall give the relation between shaft voltage and bearing current as well as shaft current measurements.

(6) If the generator is used with frequency converter systems on the rotor side, the generator shall be equipped with sliprings for shaft earthing. The sliprings for shaft earthings should be installed at the NDE (non-drive end) or both sides of the generator rotor.

(7) The equivalent circuit diagram including the parameters of the generator shall be submitted for design assessment (see Appendix 8.A).

(8) If synchronous generators are equipped with devices or other measures for short circuit limitation, the resulting electromagnetic torques (M) shall be analysed to show their function and efficiency. In this case, if a synchronous generator with separately excitation system is used, the parameters according to IEC 60034-16-3 (Figure 1) shall be submitted for assessment.

Note:

For determination of the resulting electromagnetic torque (M), see Chapter 4, Appendix 4.C.

(9) The balancing quality grade of the generator rotor (as per ISO 1940-1) shall be provided for the assessment.

8.2.3 Rating of auxiliary motors

(1) Motors shall be designed according to the operating times and temperatures to be expected. The designed duty types shall be given as specified in IEC 60034 Part 1 "Rating and Performance" or as per equivalent codes.

(2) The nominal torque (M_n) and the equivalent torque (reference torque) of auxiliary motors (e.g. pitch motor) shall be in compliance with the corresponding load calculations.

(3) For pitch motors, please refer to Section 7.2.4.5 additionally.

8.2.4 Materials

(1) The materials for the construction of electrical machines shall be suitable for the expected environmental conditions; particular attention shall be paid to the corrosive effect of a marine atmosphere. Materials unsuitable for a marine atmosphere may be used if protected by adequate coating or cladding.

(2) If plastics are used for casings, terminal boxes and fan wheels, materials suited for low temperature shall be used.

8.2.5 Ventilation and cooling

(1) Electrical machines for wind turbines shall preferably be designed in fully enclosed form. Machines with a power output exceeding 50 kW shall be provided with drain holes to prevent the accumulation of condensed water.

(2) Draught-ventilated machines may be used if the machine is designed to be resistant against incoming air with moisture, oil vapour and dust, or if the incoming air is free from such. Corresponding evidence shall be provided for assessment.

(3) The cooling circuit of the generator shall be monitored in a suitable manner.

8.2.6 Windings

(1) In conjunction with the protective devices provided, electrical machines shall be able to withstand the thermal and dynamic stresses to be anticipated in the event of short circuit. The generator manufacturer shall provide a measurement report of generator short-circuit testing or / and full load calculations including model description. For testing purposes, original protection devices are not required. The worst cases shall be tested; see Appendix 4.C. The following result values shall be given as a minimum: short-circuit torque at generator shaft, short-circuit current at rotor and stator, winding temperatures during the short circuit, maximum short-circuit duration until mechanical deformation in the air gap or at the coil ends will result in stopping the machine by welding the air gap during failure operation.

(2) Electrical machines shall be so designed and constructed that the permissible over-temperatures for the class of insulation are not exceeded, irrespective of the operating time. The values listed in IEC 60034-1 shall be used as guideline values.

(3) If the winding temperature is monitored with regard to its limiting values, thermistors or equivalent sensors should be used. Thermal overcurrent relays with bimetallic elements are not suitable.

8.2.7 Bearings and couplings

(1) The verification of the bearings shall take place in accordance with Section 7.3.

(2) To avoid damage to bearings, it is essential to ensure that no harmful currents can flow between bearings and the shaft and that the coupling is of an insulated type.

The bearing current density J for the bearings of electrical machines shall be smaller than 0.1 A/mm^2. Corresponding calculations shall be provided for assessment.

(3) The bearing temperature shall be monitored in a suitable manner. Thermistors or equivalent sensors shall be used.

8.2.8 Generator testing

(1) Generator types for wind turbines shall be thermal- and performance-tested according to IEC 60034-1 “Rotating electrical machines”. The measurements shall be performed by staff who are independent of the production or design team.

(2) If the machines are operated at frequency converters, the increased warming caused by the additional harmonics shall be taken into account during the type test as follows:

- Worst-case operating conditions for voltage and power factor, as normally defined in the design documentation of the wind turbine, shall be applied during the test. This refers to the lowest tolerable operating voltage and currents with the maximum capacitive power factor.
- When carrying out the thermal performance test of the machine, the frequency converter that is used in the wind turbine should be operated at the same time and according to the worst-case operating conditions.
- If a thermal performance test under the above mentioned conditions is not possible for technical reasons, calculations are permissible as an alternative. Methods and corresponding calculations shall be provided for assessment (e.g. IEC 60034-29).

(3) The overspeed test according to IEC 60034-1 subclause 9.7 shall be performed with each generator type used for wind turbines:

- for 2 minutes
- with the highest speed, either according to Table 18 of IEC 60034-1 based on the maximum rated speed of n_3 as defined in Section 2.2.2.6, para 1 of this GL Guideline or with n_{max} as defined in Section 2.2.2.6, para 6 depending on which value is the higher one. See also Section 8.2.2, para 3 for the speed rating.

- vibration measurements before and after the overspeed test (as per IEC 60034-14)

- As an alternative, the overspeed test can be also performed during balancing (balancing test before and after overspeed run on the balancing machine).

(4) Routine tests shall be performed during the production, with the minimum scope as given in IEC 60034-1, subclause 9.1.

(5) Additionally, a routine test / overspeed test of at least every 10th generator should be performed as per para 3.

Note:

Expanded operating ranges for power factor and voltage are often the result of local requirements given in so-called Grid Codes. These requirements have an influence on the turbine design and must therefore be considered at an early design stage.

8.3 Power Transformers

8.3.1 General

(1) To an increasing extent, the power transformers are being integrated into the wind turbine itself. If this is the case and if power transformers with an apparent power greater than 100 kVA are installed within the tower or the nacelle of a wind turbine, they fall within the scope of the assessment and shall meet the requirements set out below. Power transformers do not fall within the extent of the assessment if they are installed outside of the wind turbine.

(2) Transformers shall comply with the latest version of international standard series IEC 60076. This shall be verified through type test records containing at least the following tests:

- Temperature-rise test
- Dielectric type tests
- (Lightning impulse test for dry-type transformers)

Test conditions and results of these tests will be assessed and shall comply with the requirements of IEC 60076.

(3) Data and information given on the nameplate shall be in accordance with the requirements of IEC 60076. A corresponding nameplate shall be placed at each transformer.

(4) When additional air-cooling with fans is provided, the transformer nameplate shall display the nominal power rating both with and without fans.

(5) Power transformers shall be so designed and constructed that the permissible over-temperatures for the thermal class are not exceeded, irrespective of the operating time. Depending on the wind turbine design, the transformer might be operated at a frequency converter. The increased warming caused by the additional harmonics shall then be taken into account for the temperature-rise test e.g. by applying IEC 61378-1 in addition to Section 8.3.1, para 2.

8.3.2 Installation

(1) Power transformers shall be installed in separate rooms which can be locked and which are accessible to authorized personnel only. The installation locations for power transformers shall be well cooled. The access to the transformer room should only be possible with the power transformer switched off.

(2) An exception to Section 8.3.2, para 1, can be made for power transformers of encapsulated or insulated design, but this has to be approved by GL in each individual case.

(3) The fastening torque for cable connection terminals of power transformers shall be specified and included in the design and commissioning documentation; please also refer to Section 8.7.5.1, para 1.

(4) Power transformers installed in wind turbines are exposed to a higher level of vibration compared to other locations. This shall be considered for the design and installation of the transformer. Confirmation by the transformer manufacturer that the transformer can be operated within wind turbines shall be provided for certification.

Note:

When erecting wind turbines with power transformers contained inside the tower or nacelle, the relevant national regulations shall be taken into account. Reference shall be made to e.g. VDE 0101 in the case of Germany. However, this does not fall within the scope of a GL assessment.

8.3.3 Protection

(1) Power transformers shall be protected against short circuit and overload.

(2) It should be possible to switch off power transformers on all sides. Installations shall have facilities that allow a separation of this equipment on all sides if voltages can be applied on more than one side.

(3) Power transformers shall be fitted with temperature monitoring.

(4) Transformers shall be protected against transient overvoltages and electrical stress on the insulation.

8.3.4 Dry-type power transformers

(1) In addition to Section 8.3.1, para 2, IEC 60076-11 “Dry-type transformers” shall be applied for the design.

(2) The transformer shall be able to withstand the conditions in the wind turbine without accelerated ageing or weakening of the electrical insulation system (EIS) including the insulation of all transformer terminals, to prevent fire from being caused by the transformer. Such conditions are:

- salty (and / or wet) air from outside which might come in contact with the EIS
- pollution on the EIS from moisture, dust, coal powder and brake lining in the concentrations occurring inside the transformer enclosure
- vibrations

Note:

This can be achieved best by using a protection degree of IP 55 for the transformer including transformer terminals and connection terminals. Transformer cooling shall be implemented accordingly, taking into account possible condensation (see Section 2.3.2.17).

(3) The power transformer shall be self-extinguishing. The fire class shall be F1 according to IEC 60076-11, where applicable.

(4) If the power transformer is not designed with a protection degree of IP 55 or higher, one of the following issues shall be fulfilled:

- The enclosure of the transformer, including any internal cooling system, shall be designed with protection degree IP 55 or higher.
- regular cleaning (from salt and dirt) of the EIS surfaces in such a way and such a frequency to achieve sufficient surface resistance on the EIS to maintain the electrical integrity
- increased surface insulation level of the EIS to withstand a permanent earthed insulation surface with a permanent and very low surface resistance

Note:

The test E2 and C2 according to IEC 60076-11 is not a sufficient test when the electrical surface resistance is permanently reduced by pollution and / or condensation on the EIS.

8.3.5 Liquid-immersed power transformers

(1) Liquid- immersed power transformers shall be provided with a collecting arrangement which permits the proper disposal of the liquid.

(2) Liquid- immersed power transformers should be fitted with protection against the outgassing of the liquid.

(3) The liquid temperature shall be monitored. An alarm shall be actuated before the maximum permissible temperature is attained. When the temperature limit is reached, the transformer shall be disconnected.

(4) The liquid filling level shall be monitored.

8.4 Frequency Converters

8.4.1 General

(1) Frequency converters are power semiconductor converter systems (PSCSs) as defined in IEC 62477-1 (concerning the clauses and subclauses of this IEC named within this section the edition CDV of this IEC shall be applied, issued 2010-01-22 and named 22/168/CDV:2010). Frequency converters are normally used in pairs: one being connected to the rotating electrical machine and one to the internal grid. Both are interconnected by a DC bus, backed by power capacitors. Correspondingly, a machine-side converter and a grid-side converter shall be considered. Grid-side and machine-side converters can be designed as parallel modules or as one single module.

(2) Sections 8.4.1 to 8.4.6 apply for main frequency converters when used within the wind turbine in connection with the generator. When used in connection with other systems, only Section 8.4.7 is applicable.

(3) For frequency converters with voltages above 1000 V AC or 1500 V DC, IEC 61800-4 shall be applied.

(4) Power electronics shall be designed in accordance with the electromagnetic immunity requirements and requirements for electromagnetic emissions (electromagnetic compatibility, EMC). The relevant EMC requirements are given in IEC 61800-3.

The manufacturer of the frequency converter shall evaluate the results proving that the EMC requirements are fulfilled. This shall be stated by the manufacturer of the frequency converter. This statement shall be provided for GL assessment.

Based on the test results concerning EMC, the manufacturer of the frequency converter shall require corresponding measures that have to be observed during installation or assembly. At a minimum, the shielding of connecting cables shall be defined in detail by the frequency converter manufacturer. This is verified by GL in the witnessing of the Implementation of design-related requirements in Production and Erection (IPE).

(5) According to Section 4.5.4.3, para 3, the frequency converter or its control system may be applied for testing of the load-relevant control and safety system functions (LRF).

8.4.2 General design and data to be provided

(1) Protective earthing shall be designed according to IEC 62477-1 subclause 4.4.6.3 (protective earthing conductor). Assessment shall be performed using a confirmation of this by the frequency converter manufacturer. GL will verify this in the IPE at the frequency converter manufacturer’s workshop. Minimum requirements are given in IEC 62477-1, subclause 6.3.6.3 (protective earthing conductor current).

(2) Protective bonding shall be designed according to IEC 62477-1 subclause 4.4.6.2.2: (rating of protective bonding) and tested by the frequency converter manufacturer according to subclause 5.2.3.11 (protective bonding tests, type test and routine test). GL assessment will be done based on corresponding test reports during design assessment. The implementation shall be checked during the IPE at the frequency converter manufacturer’s workshop.

(3) The design concerning the connections between frequency converter and wind turbine as defined in IEC 62477-1 subclause 6.3.5 (power conductor type, size, amount of cables etc.), shall be provided by the frequency converter manufacturer for GL assessment. The implementation will be inspected by GL during the IPE at the wind turbine manufacturer’s workshop.

(4) The frequency converter manufacturer shall state the pollution degree for which the frequency converter has been designed.

Table 8.4.1 Definitions of pollution degree

Pollution degree	Description
1	No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.
2	Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation is to be expected.
3	Conductive pollution or dry non-conduc-tive pollution occurs which becomes conductive due to condensation which is to be expected.
4	The pollution generates persistent conductivity caused, for example by conductive dust or rain or snow.

(5) Statement and definition of environmental conditions shall be given according to IEC 60721. Guidance and minimum scope of documentation can be found in IEC 62477-1, subclause 4.9.1.

(6) Insulation design shall be rated according to IEC 62477-1. For this, the impulse withstand voltages and temporary overvoltages shall be defined and tested for main power circuits. The impulse withstand voltages and the temporary overvoltages shall be determined according to Table 10 in IEC 62477-1 subclause 4.4.7.1.5: insulation voltages). For this, the system voltage has to be defined.

(7) The system voltage of the machine-side converter shall not be less than the rms value of the maximum no-load voltage between phases at the highest possible speed n_{max} (according to Section 2.2.2.6 of this Guideline) or at minimum speed occurring with the generator being connected at wind speeds above v_{in}, according to Section 2.2.2.6 of this Guideline, whichever is more severe.

(8) The system voltage of the grid-side converter shall be determined by the manufacturer of the frequency converter according to IEC 62477-1, subclause 4.4.7.1.6.1 and provided for Design Assessment.

(9) The overvoltage category according to IEC 62477-1 shall be OVC IV for the machine-side converter and OVC III for the grid-side converter.

(10) Clearance distances shall be designed according to subclause 4.4.7.4 of IEC 62477-1 creepage distances according to subclause 4.4.7.5 of IEC 62477-1 This shall be documented by a corresponding statement to be submitted by the frequency converter manufacturer. This statement shall contain the following information:

- CTI (comparative tracking index) according to subclause 4.4.7.5.1 of IEC 62477-1 and subclause 6.2 of IEC 60112 for all parts of the main power circuit inside the frequency converter
- pollution degree according to Table 1
- listing of the electrical schematics used, including their latest revision dates
- details on the method of installation e.g. “printed wiring board (PWB)”

(11) For the high-power circuits, bus bars and coils, solid insulation material shall be used which has a proven performance according to subclause 4.4.7.8 of IEC 62477-1. The corresponding documentation shall be submitted for Design Assessment and inspection by GL at the IPE.

(12) In the case of plugs or similar devices that can be disconnected without the use of a tool, and in case the withdrawal of these results in the exposure of conductors (e.g. pins), the discharge time shall not exceed 1 s, otherwise such conductors shall be protected against direct contact as per IPXXB at least. If neither a discharge time of 1 s nor a protection of at least IPXXB can be achieved, disconnecting devices with an appropriate warning shall be applied instead.

(13) The cooling principle shall be described and provided for design assessment.

(14) Cooling shall comply with subclause 4.7.2.2 (coolant) of IEC 62477-1.

(15) When the coolant is intentionally in contact with live parts (for example non-earthed heat sinks), the conductivity of the coolant shall be continuously monitored and controlled, in order to avoid hazardous current flow through the coolant.

(16) Distance between terminals of main power flow and obstruction toward which the wire is directed upon leaving the terminal shall be at least that specified in Table 2, with compliance to be checked by the IPE.

Table 8.4.2 Wire bending space from terminals to enclosure

Size of wire mm^2	**Minimum bending space, terminal to enclosure mm**		
	Wires per terminal		
	1	**2**	**3**
10 – 16	40	-	-
25	50	-	-
35	65	-	-
50	125	125	180
70	150	150	190
95	180	180	205
120	205	205	230
150	255	255	280
185	305	305	330
240	305	305	380
300	355	405	455
350	355	405	510
400	455	485	560
450	455	485	610

(17) If a DC chopper is used to convert excess energy to heat (e.g. to reduce mechanical loads), the design shall be described for A-Design Assessment.

At a minimum, the following details shall be given: maximum power and maximum operation time at full power, resistance range to be set, cooling time after full-power maximum-time operation, and cooling principle. All trigger values and trigger situations shall be given.

(18) The current flowing through generator bearings and generator shaft shall be analysed and possible paths shall be described. This analysis shall consider the measured shaft current and touch current from the converter, to be measured during the joint heat-run type test of the generator and frequency converter (see Section 8.4.5, para 7, 8.2.8, para 1 and 2).

(19) The maximum value of voltage steepness (dU/dt) shall be given and verified by measurement, see Section 8.4.5, para 8.

(20) The following data shall be provided for Design Assessment of both the machine-side converter and the grid-side converter:

- name and address of the frequency converter manufacturer
- type of the frequency converter (e.g. IGBT 4-quadrant operation)
- designation of frequency converter (e.g. Wind Converter 57HXY)
- generator manufacturer’s name and address
- generator type (e.g. doubly fed induction generator)
- generator designation (e.g. Wind Generator ABM6H)
- generator power rating
- details of filters necessary
- number of units connected in parallel
- rated apparent power per module
- rated maximum frequency
- rated minimum frequency
- rated current per module at maximum frequency
- rated current per module at minimum frequency
- maximum and minimum prospective short-circuit current rating of the machine-side converter AC port and the grid-side converter AC port according to IEC 62477-1, subclause 4.3.2.1 (Specification of prospective short-circuit current, input ports)
- rated voltage or range at maximum frequency
- rated voltage or range at minimum frequency
- maximum voltage of the DC bus
- technical data of the DC bus capacitors (data sheet)
- crowbar and chopper resistance, if applicable
- cooler manufacturer
- cooling type
- rated thermal power of the cooler
- rated electrical power of the cooling system (fans, pumps etc.)

8.4.3 Protection equipment

(1) All power electronics shall be protected against overload and short circuit. It shall not be possible for a semiconductor element to be destroyed in the event of a single malfunction outside the element itself. Protection of the installation may be achieved by fuses, circuit breakers or the intervention of the control system.

(2) Single-phase protection equipment is not acceptable for 3-phase installations. Exceptions can be made if other mechanisms ensure that three-phase tripping takes place, even in the case of one-phase faults. If fuses are used, a corresponding mechanism shall be implemented

(3) The protection equipment shall ensure that, in the event of a disconnection, the energy stored in the components and the load circuit cannot have a damaging effect and that, in the event of a failure of essential components, the wind turbine is brought to a standstill in a controlled manner and damaged subsystems are switched off as selectively as possible.

(4) Self-test facilities are required for voltage loss, overvoltage and overcurrent protection equipment as well as for communication failure to safeguard the function of the protection equipment.

(5) Section 8.7 shall apply as far as is relevant.

(6) The principles used to fulfil Section 8.4.3, para 1, 2, 3, 4 and 5 shall be described. This description shall be submitted by the frequency converter manufacturer. It shall be assessed during Design Assessment and implementation shall be verified by GL during the IPE.

(7) In accordance with E DIN IEC 60364-5-53 “Low-voltage electrical installations – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control (IEC 64/1486/CD:2005)”, semiconductor devices shall not be used for the purpose of isolating from power sources.

Note:

For the selection of RCD or RCM (residual current protection), guidance concerning typical failure current waveforms is given in IEC 62477-1, Annex H, and in subclause 4.4.8.

(8) Capacitors located behind panels that are removable for servicing, installation, or disconnection shall present no risk of electric energy hazard from charge stored on capacitors after disconnection of the frequency converter. They shall be discharged to a voltage less than that given in Table 8 of IEC 62477-1 (IEC 22/142/CD final draft, circulated December 19th, 2008), within 5 s after the removal of power from the frequency converter (Table 8 – Values of accessible capacitance and charging voltage (threshold of pain)). If this requirement is not achievable for functional or other reasons, then Section 8.4.6, para 3 shall apply.

(9) Capacitors within a frequency converter shall be discharged to an energy level of less than 20 J, as set out in IEC 62477-1, subclause 4.5.1.2, within 5s after the removal of power from the frequency converter. If this requirement is not achievable for functional or other reasons, then Section 8.4.6, para 3 shall apply.

(10) Conformity with Section 8.4.3, para 8 and 9 is checked by GL when inspecting the frequency converter and relevant circuit diagrams, taking into account the possibility of disconnection with any ON/OFF switch in either position and no operation of periodic power-consuming devices or components within the frequency converter or supervisory control.

The corresponding calculation shall be submitted for Design Assessment.

If the capacitor discharge time cannot be accurately calculated, the discharge time shall be measured by an accredited laboratory and the report shall be submitted for Design Assessment.

(11) If a crowbar is used for protecting the frequency converter against excessive currents or voltages in the generator rotor, the design shall be described for A-Design Assessment. At a minimum, the trigger values, resistance and maximum operation time shall be given, as well as minimum cooling time after maximum operation time.

Note:

If load case DLC 9.2 (see Section 4.3.3.9, para 2) is considered adequate, measurements shall be carried out on the wind turbine level to verify these load calculations.

8.4.4 Routine testing

(1) Each frequency converter shall be routine-tested after production. Routine tests in production should contain the following items at a minimum:

- tightness of cooling system, except for air-cooled frequency converters
- plausibility checks of voltage waveform and phase angle
- preloading and discharging of DC capacitors
- test of grid synchronization and preferably
- heating test, showing the proper heating behaviour of the power semiconductors with the cooling system running

(2) The routine tests of the frequency converter shall be witnessed by GL during the IPE.

(3) The protective bonding impedance shall be measured according to subclause 5.2.3.11.3 of IEC 62477-1. This shall be done as part of the routine test. The test result shall be compliant with the requirements given in subclause 5.2.3.11.1.2 of IEC 62477-1. If the result is not compliant with these requirements, an exception is possible in the following case:

The converter is fully assembled in a closed switchboard by the converter manufacturer and the connection to the protective earthing system of the wind turbine is effected by more than one means (e.g. by two or more protective bonding cables).

(4) The routine test report of one sample frequency converter (the type under assessment or a similar type) shall be provided for Design Assessment; working instructions shall be provided and will be inspected during the IPE at the frequency converter production factory.

8.4.5 Measurement and type testing

(1) Type testing of the frequency converter shall be performed in order to verify design assumptions for this component. The measurements shall be performed by staff who are independent of the production or design team. The place of testing will be usually the factory of either the frequency converter or the generator.

The following test reports shall be submitted for A-Design Assessment.

(2) The design of the protective bonding shall be tested according to Section 8.4.2, para 2 (protective bonding test, type test).

(3) The touch current in the protective earthing conductor shall be determined according to IEC 62477-1 subclause 4.4.6.4.2 (touch current in case of failure of protective earthing conductor) and measured according to Section 5.2.3.7 (touch current measurement). The report shall be provided for Design Assessment.

(4) For Design Assessment, the submission of test reports of successful testing according to the following subclauses of IEC 62477-1 is necessary: 4.4.7.8.3.4 (compliance); 5.2.3.2 (impulse voltage test); 5.2.3.4 (A.C. or D.C. voltage test); 5.2.3.5 (partial discharge test). During assessment and IPE, the hardware tested will be compared with the hardware used in the wind turbine.

(5) Type testing should be performed in the following order immediately after each other: first the heat run, then voltage testing and finally partial discharge testing.

(6) If other coolants than air are used, the hydrostatic pressure test according to subclause 5.2.7 and the loss of coolant test according to subclause 5.2.4.9.4 of IEC 62477-1 shall be passed successfully as a type test and the reports shall be submitted for Design Assessment.

(7) The temperature rise test (see also Section 8.2.8, para 1 and 2) shall be performed together with the generator type under assessment according to subclause 5.2.3.10 of IEC 62477-1 for the operational mode with the highest operating temperature. This operational mode shall be described, giving frequency, voltage and current at a minimum. The test shall be performed together with the generator and all relevant filters.

Subclause 4.6.4.1 and Table 14 of IEC 62477-1 shall be observed (maximum measured total temperatures for internal materials and components).

During the temperature rise test, the parameters specified in Section 8.4.5, para 8, 9, 10, 11 and 8.4.2, para 18 shall be measured additionally. The corresponding test report shall be submitted for Design Assessment.

(8) The maximum voltage steepness during normal operation (see Section 8.4.2, para 19) shall be measured at the machine-side and grid-side converters of the type, stated in a measurement report and submitted for Design Assessment. The measurement shall be performed together with the filters used. The rating of the filters shall be part of the measurement report.

(9) A frequency converter having forced cooling shall be operated at rated load with fan or blower motor or motors made inoperative, singly or in combination from a single fault, by physically preventing their rotation. This shall be done until a reaction of the frequency converter can be seen. The reaction of the frequency converter's cooling system and the resulting temperatures shall be reported.

(10) The following values shall be measured between generator and frequency converter:

- current rms values
- currents of higher frequencies than 50 Hz, measured analogously to IEC 61400-21 Edition 2, subclause 7.4 Current harmonics, interharmonics and higher frequency components (comment: "analogously" because Part 21 is valid for entire wind turbines)
- maximum possible current of the machine-side converter
- voltage of the DC bus

(11) Vibration test according to subclause 4.9 and 5.2.6.4 of IEC 62477-1 shall be performed; test reports and test specification shall be submitted for Design Assessment.

8.4.6 Installation, commissioning and maintenance

(1) Manuals shall contain at a minimum the requirement of IEC 62477-1, subclause 6.3.7 for commissioning and subclause 6.5 for maintenance.

(2) The marking and scope of data to be given on the rating plate and, in the manuals, shall be done in accordance to subclause 6 of IEC 62477-1.

(3) When the requirements of Section 8.4.3, para 8 or 9 are not met, the warning symbol ISO 7010-W001 (see Annex C of IEC 62477-1) and an indication of the discharge time (for example, 45 s, 5 min) shall be placed in a clearly visible position on the enclosure, the capacitor protective barrier, or at a point close to the capacitor(s) concerned (depending on the construction). The symbol shall be explained and the time required for the capacitors to discharge after the removal of power from the frequency converter shall be stated in the manuals.

8.4.7 Frequency converters connected to other systems than generator

(1) This subsection shall be used for all applications of frequency converters in the turbine, except the main power generator system.

(2) For frequency converters driving rotating electrical machines supplied by DC voltages, the rating plate and corresponding specifications shall be given according to IEC 61800-1 subclause 8 (product information) plus the maximum voltage change rate dV/dt in kV/µs.

(3) It shall be verified that the specifications according to Section 8.2.3 match the corresponding components to which the frequency converter is connected.

(4) For frequency converters driving rotating electrical machines supplied by AC voltages, the rating plate and corresponding specifications shall be given according to IEC 61800-2, subclause 8 (product information), plus the maximum voltage change rate dV/dt in kV/µs.

(5) For PSCSs being used for rotor blade pitching, please refer to Section 7.2.4.5 additionally.

8.5 Medium-voltage Switchgear

8.5.1 General

(1) To an increasing extent, the medium-voltage installations are being integrated into the wind turbine itself. If this is the case and if medium-voltage installations are installed within the tower or the nacelle of a wind turbine, they fall within the scope of the assessment and shall meet the requirements set out below. Medium-voltage installations do not fall within the extent of assessment if they are set up outside the nacelle and tower (i.e. are located in a transformer substation).

(2) Medium-voltage switchgear shall comply with international standard series IEC 62271. This shall be verified through type test records containing at least the following tests:

- dielectric tests
- short-time withstand current and peak withstand current tests
- internal fault

The test reports will be assessed with regard to test conditions and the results of these tests will be assessed; these shall comply with the requirements of IEC 62271. In addition, Section 8.5.2, para 2 shall be observed.

(3) Information on the nameplate shall be in accordance with IEC 62271. A corresponding nameplate shall be placed at each switchgear.

8.5.2 Protective measures and tests

(1) A risk of personal injury through electrical shock and internal arcs shall be minimized independently of the necessary protection against foreign matter and water.

(2) With reference to IEC 62271, only IAC-qualified medium-voltage switchgear shall be installed inside of the wind turbine. The test current applied shall be as high as the rated short-time withstand current of the respective type of switchgear used.

(3) Installation of the switchgear within the tower or nacelle shall be in accordance with the IAC accessibility type of the switchgear used.

(4) An exception can be made for switchgear installed in separate incombustible rooms within the wind turbine that can be locked. Access to the room shall be granted only when the wind turbine is switched off.

8.5.3 Pressure relief

(1) If the gas pressure resulting from internal arcs within the switchboard is to be vented via pressure-release flaps, the installation space shall be as specified by the switchgear manufacturer and shall have an adequate volume. Suitable measures shall be taken to ensure that the overpressure occurring within the space is limited to physiologically acceptable limits. This overpressure shall be taken into account for the structural design of the installation space.

(2) If the switchgear is designed so that the gas pressure caused by internal arcs is also, or only, released downwards, the floor shall be constructed so that it can withstand this pressure. Care shall be taken to ensure that sufficient volumes of space are available below the floor for the expansion of the internal-arc gases.

(3) Combustible materials and low-voltage cables are not admissible in the endangered area.

(4) Suitable drawings and commissioning manuals shall be provided for verification of an appropriate installation.

8.5.4 SF6 switchgear

SF6 switchgear shall only be installed in spaces which are adequately ventilated.

Note:

It shall be taken into account that SF6 is heavier than air and the gases escaping in the event of internal arcing have toxic and corrosive effects.

Reference is made to national requirements, for Germany e.g. BGV A8 and BGI 753 by BGFE (Berufsgenossenschaft der Feinmechanik und Elektrotechnik). However, this does not fall within the scope of GL assessment.

8.6 Back-up Power Supply System

8.6.1 General

(1) This section considers electrical back-up power supply systems as a functional unit comprising charging equipment and energy storage systems. It applies to back-up power supply systems installed as an independent source of electrical power for safety systems and other emergency consumers.

(2) Back-up power supply systems within the scope of this section shall be designed to cover failures of the internal or external power supply as described e.g. in Sections 2.2.2.12, 2.2.2.13, 2.2.3.4.5, 4.3.3.1, 4.3.3.9 and situations related to DLC 9.2 in general.

8.6.2 Charging equipment

(1) Only automatic chargers shall be used with charging characteristics adapted to the type of energy storage system, such as special battery types etc. Corresponding descriptions shall be submitted for GL assessment.

(2) Overcharging shall be prevented by automatic charger regulation or, if necessary, by dump loads which can be switched on. Corresponding descriptions shall be submitted for GL assessment.

(3) If consumers are supplied while charging is in progress, the maximum charging voltage shall not exceed 120 % of the rated voltage of the battery, not even during boost charging. Charging voltage of the automatic charger shall be given in the description to be submitted for GL assessment.

(4) Charging equipment shall have its own short-circuit and overcurrent protection equipment on both the input and the output side.

8.6.3 Energy storage system

(1) For rating of the energy storage system of back-up power supply systems, the internal environmental conditions to be provided according to Section 8.1.7.1, item a), the external environmental conditions according to Section 4.2.4 and the assumptions made for load case definition according to Section 4.3 shall be taken into account.

(2) For rating the energy storage system of back-up power supply systems intended for braking systems, reference is made to Section 2.2.3.4.5.

(3) The sufficient rating of the energy storage system of a back-up power supply system shall be proven on the basis of calculations. All design limits, such as maximum load current, temperature limits, discharge limits etc., shall be stated in the calculations and provided for GL assessment.

(4) Batteries, capacitor banks or other technologies used for energy storage systems shall permit an adequate number of charge/discharge cycles. The design lifetime including assumptions and calculations shall be provided for GL assessment. Exchange intervals shall be defined in the wind turbine manuals.

(5) Warning signs indicating DC voltages higher than 60 V and risks caused by batteries, if applicable, shall be provided on the enclosure of the energy storage system.

8.6.4 Installation and operation of back-up power supply systems

(1) Enclosures for back-up power supply systems shall provide a minimum protection class of IP 54 and shall be well-ventilated if they contain batteries and if there is a risk of outgassing.

(2) Back-up power supply systems shall be installed in such a way that they are accessible for maintenance work.

(3) The energy capacity and the correct functioning of back-up power supply systems shall be monitored. If they are used for braking systems, refer to Section 2.2.3.4.5 and 2.3.2.11.

(4) If capacitor banks are used for energy storage systems, the partial voltages of capacitor groups shall be monitored instead of monitoring the overall voltage of the capacitor bank. No charging shall take place during monitoring.

8.7 Low-voltage Switchgear, Controlgear and Switchboards

8.7.1 General

(1) The requirements of this section apply to low-voltage switchgear and controlgear assemblies with operating voltages of up to 1000 V AC or 1500 V DC.

(2) Stationary or movable switchboards with or without enclosure shall comply with the standards IEC 60439-1 "Low-voltage switchgear and controlgear assemblies".

(3) All components of the electrical installation shall be protected against overload and short circuit.

(4) All appliances, instruments and operating elements (e.g. sensors, limit switches) shall be permanently labelled in accordance with the corresponding circuit diagrams.

(5) Upon completion of the verification of installation, an initial report according to IEC 60364-6 shall be provided.

8.7.2 Protection

8.7.2.1 General

Overload and short-circuit protection shall be provided for each line conductor.

8.7.2.2 Short circuit

(1) The rated breaking capacity of each circuit breaker used for short-circuit protection shall not be less than the maximum possible short-circuit current at the point of installation.

(2) Short-circuit current calculations shall be carried out for the main circuit.

(3) The short-circuit calculation shall consider all possible short circuits necessary for an evaluation of the system. The following types of short circuits shall be investigated at least for:

- short circuits on the rotor and stator terminals of the generator (except for permanent magnet rotors)
- short circuits on main busbars

All data used for the short-circuit current calculation shall be submitted.

(4) The following values shall be determined according EN 60909:

- peak short-circuit current i_p
- initial symmetrical short-circuit current (I_k'')

(5) The short-circuit current calculation shall be accompanied by a list of the proposed switching devices and their characteristic data. The rated making capacity, the rated breaking capacity and the utilization category of the switching appliances shall be stated.

(6) Electric arc detection in combination with electrical value detection is recommended.

8.7.2.3 Overload

The selection of overload protection devices shall be based on the rated currents in the cable or circuit.

8.7.2.4 Overcurrent

(1) The current-time characteristics of overcurrent protection devices shall be compatible with the system components to be protected and with the requirements of selectivity.

(2) The overcurrent protection of the entire circuit (switchgear, switchboard wiring, supply cables and equipment) shall be based on the rated current I_n of the connected equipment. In the case of grouped supply cables, the protection design shall be based on the evaluated total rated current.

8.7.2.5 Selectivity

The short-circuit protection of essential equipment shall be selective and shall ensure that only the switching device nearest to the fault initiates disconnection of the defective circuit.

8.7.2.6 Residual current

Residual current protective devices (RCDs) shall be provided for socket-outlets for maintenance purposes with a rated current up to 32 A.

8.7.2.7 Back-up

Circuit breakers the making/breaking capacities of which are less than the anticipated maximum short-circuit currents shall be protected by back-up fuses of sufficient breaking capacity.

8.7.3 Switching devices

8.7.3.1 General

(1) The making and breaking capacity of switchgear shall be stated by the manufacturer and entered into the assessment documentation.

(2) The rated current values of fuses shall be stated. The set values of the adjustable protection equipment shall be stated in the circuit diagrams and permanently marked on the device.

(3) Switches and circuit breakers in three-phase circuits shall disconnect all phases simultaneously.

8.7.3.2 Switches

Switches shall be rated for at least the rated current of the back-up fuse.

8.7.3.3 Circuit breakers

(1) The rated making capacity of a circuit breaker shall not be less than the maximum asymmetric short-circuit current which may occur at the point of installation.

(2) The setpoints of adjustable protection devices shall be permanently marked either on the scales or on plates fixed nearby.

(3) In the case of a fault in the circuit breaker on the low-voltage side of the power transformer, the medium-voltage switchgear shall trip.

8.7.3.4 Fuses

(1) Fuse links shall have an enclosed fusion space.

(2) Fuses for overload protection shall be used only up to a rated current of 315 A.

8.7.3.5 Motor-circuit switches

(1) Motors with a power rating of more than 1 kW shall be individually protected against overloads and short circuits.

(2) Regardless of its rating, every motor shall be protected by a suitable short-circuit protection device.

8.7.4 Distribution panels

8.7.4.1 General

(1) Electrical components mounted in the doors of switchboards for voltages over 50 V shall be safeguarded against accidental contact. Such doors shall be earthed.

(2) Electric equipment and fuses shall be safely accessible.

(3) For circuit breakers and load-switches, the minimum distances above the arc chutes specified by the manufacturers shall be kept free.

8.7.4.2 Protection class

(1) The degree of protection of an enclosed assembly against contact with live parts shall be at least IP2X according to IEC 60529. This shall be assessed during witnessing of the commissioning.

(2) The degree of protection of an enclosed assembly against water shall be at least

- IPX1 in the tower
- IPX2 in the nacelle
- IPX4 in the hub

according to IEC 60529. This shall be assessed during witnessing of the commissioning.

(3) Unless specified otherwise, the degree of protection indicated by the manufacturer applies to the complete assembly when installed in accordance with the manufacturer’s instructions, for example sealing of the open mounting surface of an assembly, if necessary.

8.7.4.3 Climate

(1) During operation, the air temperature in enclosed switchboards shall not exceed +45 °C and shall not fall below -5 °C. Otherwise all components shall be verified concerning their operation conditions.

(2) For details, also about the applicable withstand temperatures when switched off, see Section 4.2.4.1.

8.7.4.4 Tests

To verify the characteristics of a switchboard, type tests shall be performed according to IEC 60439-1. The measurements shall be performed by staff who are independent of the production or design team. The test reports shall be submitted for GL assessment.

8.7.5 Electrical apparatus

8.7.5.1 Terminal bars

(1) All screws and other connections shall be safeguarded against mechanical stress by vibration. Small screws up to M4 may be locked using varnish.

(2) To prevent conductors being squeezed off, terminals shall have backing plates, or the conductors shall be fitted with protective sleeves or equivalent protection for the wires.

(3) Protective earthing shall be provided by means of earth terminals or earth bars. Earth terminals shall be clearly marked as such.

(4) Screws carrying electrical current shall be marked to indicate that proper torque was applied.

(5) Live parts that are under voltage after the main circuit breaker has been switched off shall be insulated and marked with a warning plate at the terminals.

8.7.5.2 Conductors

(1) All conductors shall be fixed so that they are vibration-proof and shall be kept away from sharp edges.

(2) Conductors leading to equipment mounted in doors shall be laid in a tension-free manner.

8.7.5.3 Busbars

Busbars shall be mounted in such a way that they withstand the stresses caused by short-circuit currents and maintain the required clearance and creepage distances relative to other voltage-carrying or earthed components. Calculations or tests shall be provided for assessment.

8.7.6 Control, measuring and indicating circuits

(1) Control circuits shall generally be equipped with separate short-circuit protection up to a maximum of 10 A. Joint fuse protection of control and load circuits is permissible if the joint back-up fuse has a maximum rating of 10 A.

(2) Measuring and indicating devices shall generally be provided with their own circuits, to be protected by separate fuses against short circuits.

8.7.7 Safety-related parts according to 2.1.4

(1) The scope of this Section 8.7.7 is based on the listing of all electric and electronic components of the SRP/CS according to Section 2.1.4, para 3 and other electric and electronic components of other SRP/CS if provided by the wind turbine manufacturer for GL assessment.

(2) The design of the safety-related parts within the electrical installations shall be analysed under consideration of:

- the responsible parts in the circuit diagram
- the ability of the responsible parts of detecting or tolerating faults
- redundancy, robustness, diversity and monitoring

GL will verify the design of the safety-related parts of a control system for plausibility.

(3) Documentation necessary for the plausibility verification according to Section 8.7.7, para 2 shall be submitted for A- or B-Design Assessment.

8.8 Cables, Lines and Accessories

8.8.1 General

(1) Cables, lines and accessories should be selected in accordance with the environmental conditions expected at the installation site.

(2) Cables, lines and accessories installed in the tower or nacelle outside of enclosures shall be resistant to operating fluids such as oil and grease.

(3) In the case of cables, lines and accessories installed and laid outdoors or installed within lattice towers, UV resistance shall be ensured.

(4) The rated voltage of cables, lines and accessories shall not be below the rated operating voltage of the circuit involved. For circuits with variable voltage, the maximum voltage occurring during operation is decisive.

(5) The technical documentation shall state the cables and lines used, together with their standard designation and current-carrying capacities. Furthermore, the conductor cross-sections and voltages shall be entered in the schematics. This shall be done for all high-power and safety circuits as required in Section 8.1.7.

8.8.2 Selection of cables, lines and accessories

(1) Cables, lines and accessories relating to the main power distribution path shall comply with the IEC publications listed in para 2 and 3. These standards shall be applied by the cable manufacturer, who shall state corresponding compliance on his data sheet. Other cables or lines may be used if their material and construction complies with equivalent standards (e.g. German VDE) and if verification of their suitability for the application is provided.

(2) Low-voltage installations:

- IEC 60227 “Polyvinyl chloride insulated cables of rated voltages up to and including 450 / 750 V”
- IEC 60228 “Conductors of insulated cables”

(3) Medium-voltage installations:

- IEC 60502 “Power cables with extruded insulation and their accessories for rated voltages from 1 kV (*U*m = 1.2 kV) up to 30 kV (*U*m = 36 kV)”

8.8.3 Documents to be submitted for A-Design Assessment

a) torsion resistance test log or report for those lines connecting rotating parts (nacelle) with parts of the fixed structure (tower)

b) proof of oil resistance based on a declaration or certificates or test reports (e.g. based on IEC 60502) of the manufacturer for those types of cables, lines and accessories likely to be exposed to contamination with operating fluids

c) proof of UV resistance based on a declaration or certificate for cables, lines and accessories installed within a lattice tower by the manufacturer of the corresponding cable, line or accessory

d) proof of the current-carrying capacity of main power cables, with consideration of the laying method and installation. Proof can be provided by applying the standard IEC 60287 or IEC 60364-5-52. An installation or routing plan of main power cables including routing and indication of mature fix points shall be provided, too. Worst-case operating conditions, such as the minimum tolerable operating voltage and maximum capacitive power factor, shall also be considered for the determination of sufficient current-carrying capacity of main power cables and lines.

e) data sheet according to Section 8.8.2

8.8.4 Loading and protection of cables and lines

(1) Cables and lines shall be protected against short circuit and overcurrent (Section 8.7.2 shall be applied analogously). If overcurrent protection is already provided in the circuit for the equipment, short-circuit protection shall be added. This shall be designed in accordance with the short-circuit loads at the point of installation.

(2) For the rating of cables and lines, consideration shall be given to the loads expected during operation corresponding to the consumer demand, taking into account the duty of the electrical units connected. Values on the rating plates of generators and consumers shall be considered as a basis.

(3) For cables and lines subjected to twisting during operation, a control device shall be provided which protects against exceeding permissible limits. In terms of its operation, the installation shall be so designed that resetting to the neutral position is possible (see Section 2.3.2.12).

8.8.5 Laying and installation of cables and lines

(1) Multi-core cables or lines shall preferably be used for AC systems. If single-core cabling is provided instead, the following points shall be observed:

- The cables shall not be armoured with or sheathed in magnetic material.
- Non-magnetic clamps shall be provided.
- The cables of a given circuit shall be laid contiguously and shall be arranged in the same tube or cable duct.
- Single-core parallel cables shall be of the same type, length and cross-section.

(2) Cables and lines shall be secured in such a manner that no unacceptable tensile, flexural, compressive or crushing stresses arise. Corrosion-proof or permanently corrosion-protected clips or mounts shall be used for weather-unprotected and outdoor installations.

(3) Extraordinary mechanical demands, such as increased tensile or torsion stress, operationally required mobility and increased risk of mechanical damage, shall also be taken into account.

(4) For cables suspended freely without additional strain relief, the suitability of the type of cable used shall be verified. The possibility of ice loading shall be taken into account in this context.

(5) If cables or lines are laid in metal tubes or ducts, these shall be earthed effectively. Warming of such cables shall be considered during design stage and selection (see Section 8.8.3).

(6) The tubes shall be smooth on the inside and so protected at the ends that there is no risk of damage to the cable sheathing.

(7) Where there is a risk of mechanical damage, cables and lines shall be effectively protected by coverings or heat shrinks, protection tubes or equivalent.

(8) Strain relief devices of exposed cables shall be permanently protected against corrosion.

(9) Suspended cables shall be properly protected against damage and unacceptable constriction of the cable sheath.

(10) The minimum specified bending radius of cables shall be observed for installation.

8.9 Lightning Protection

8.9.1 General

(1) The lightning protection system shall comply with the international standard IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection” insofar as this section does not deviate from the IEC document. This will be assessed by GL at a minimum with respect to the requirements given in this section. National requirements in excess thereof and any additional requirements of the grid operators shall be observed but cannot be assessed during Type Certification. The main deviations between this Guideline and IEC 61400-24 are: High-voltage arc testing at the rotor blade according to subclause 8.2.3 of IEC 61400-24 is recommended but not required, provided the receptor is designed according to Section 8.9.3.1, para 4 and the conditions of Section 8.9.3.1, para 1 are met; Testing of the lightning protection system within the rotor blades according to Section 8.9.3.1, para 2.

(2) Any measurements shall be performed by staff who are independent of the production or design team.

8.9.2 Basic design criteria

8.9.2.1 Lightning protection level (LPL)

(1) The wind turbine and its sub-components shall be protected according to the lightning protection level I (LPL I). A corresponding set of maximum and minimum lightning current parameters is to be found in IEC 62305-1 “Protection against lightning – Part 1: General principles”, table 5 and 6.

(2) It is also sufficient to protect the wind turbine or single sub-components of the wind turbine according to a lightning protection level other than LPL I when effectiveness is proven by a lightning exposure assessment as described in IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection”, Clause 7 and if this can be shown to comply with the conditions at each site at which the wind turbine type may be erected.

8.9.2.2 Lightning protection zone (LPZ)

(1) The wind turbine manufacturer shall establish a lightning protection zone concept following the principles given in IEC 62305-4 “Protection against lightning – Part 4: Electrical and electronic systems within structures”, Clause 4 and discussed in the context of lightning protection of wind turbines in IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection”, Annex E.

(2) The definition of the lightning protection zones is given in IEC 62305-4 “Protection against lightning – Part 4: Electrical and electronic systems within structures”, subclause 4.2. Each lightning protection zone has the task of reducing the electromagnetic field and the conducted emission disturbances to the stipulated values. The requirements for choosing the one or the other lightning protection zone depend on the electromagnetic disturbance immunity of the equipment installed in the higher lightning protection zone. Thus, the manufacturer shall state the voltage protection level, the discharge current and the impulse current of each LPZ and additionally the equipment with the lowest immunity level within each zone and the corresponding immunity level.

(3) At each zone boundary, it must be ensured that cables and wires crossing the boundary do not conduct large parts of the lightning current or voltage transients into the lightning protection zone with the higher number. This is achieved by means of proper bonding and shielding practices and surge protection devices (SPD) of all cables and wires at the zone boundary.

(4) SPD protection is always required for all incoming cables at the entrance of a lightning protection zone. The number of required SPDs can be reduced by connecting or extending zones.

(5) Lightning protection zones can be interconnected via shielded cables (with the shield connected to the bonding system at both ends) or metallic conduits. Also, a lightning protection zone can be extended with a shielded cable to include an external metal sensor housing. The measures for connection and extension of lightning protection zones taken by the designer shall be stated in the lightning protection documentation of the wind turbine and additionally all shielding measures shall be shown in the wiring diagrams. Examples for connected zones or extended zones can be found in IEC 62305-4 “Protection against lightning – Part 4: Electrical and electronic systems within structures”, subclause 4.2.

(6) Lightning protection zones LPZ 0_A and LPZ 0_B typically include the following areas:

- rotor blades including the rotor hub cover and the internals (sensors, actuators etc.)
- the outer part of the nacelle cover
- if there is no metallic housing nor mesh or metallic reinforcement, then all facilities in the nacelle (generator, auxiliary drives, cables, sensors and actuators), the outer parts of metallic switch cabi-

nets, and the inner parts of non-metallic switch cabinets

- sensors for wind measurement (if no further protection is provided, see Section 8.9.2.1, para 7)
- inside of lattice tower
- cable connections in the soil or overhead lines between the wind turbine and the operation buildings or transformer substations, if no shielding measures are provided

(7) Lightning protection zone LPZ 1 typically includes the following areas:

- internals of the rotor hub (sensors, actuators etc.), provided that effective lightning-conducting, shielding and SPD measures are taken
- the interiors of completely metal-clad nacelle housings or sufficient metal shielding mesh with the corresponding lightning-conducting and SPD measures
- the interior of all metal-clad equipment, insofar as they are connected in a suitable manner to an equipotential bonding system (e.g. the machine foundation as the bonding level) and SPD protection
- shielded cables, or cables which are laid in metallic pipes whereby mesh shields or metallic pipes shall be connected to the equipotential bonding of LPZ 1 zones on both sides
- the sensors of wind measurement facilities, insofar as these are fitted with lightning cages, appropriate conductors sheathed in a metal shield with both sides of the shield bonded to the turbine earthing system and SPDs
- the interior of tubular steel towers or reinforced concrete towers, if designed according to applicable standards and connected to the earth electrode, equipotential bonding and protected by SPDs

(8) Lightning protection zone LPZ 2 includes facilities within lightning protection zone LPZ 1, if additional protection measures have to be taken for a further reduction in the effects of electromagnetic fields and overvoltages.

8.9.3 Lightning protection of sub-components

8.9.3.1 Rotor blade

(1) The lightning protection system of the rotor blade shall be sufficient to enable the blade to withstand lightning flashes according to the assigned lightning protection level of the wind turbine without structural damages that would impair the function of the blade. This has to be proven according to the measures set out in IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection”, subclause 8.2.3. Such proof is not necessary if no carbon is used according to Section 8.9.3.1, para 8 and if the case according to Section 8.9.3.1, para 4 applies and no proof according to IEC 61400-24 subclause 8.2.3 was provided so far. Nevertheless, such proof, with the corresponding high-voltage and high-current testing, is strongly recommended.

(2) The down-conductor system and the air-termination system have to withstand the operational demands of the blade. This shall be proven by mechanical testing of the blade with the fully assembled lightning protection system (see IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection”, subclause 8.2.4.1 and 8.2.4.2). This shall be done by installing the lightning protection system in the rotor blade before testing according to Section 6.2.5.2, para 8 of this Guideline or according to IEC TS 61400-23.

(3) The air-termination system shall be built according to IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection”, subclause 8.2.4.1.

(4) If a discrete air-termination system is used and no proof according to Section 8.9.3.1, para 1 was provided so far, the following minimum requirements for placement of a sufficient amount of receptors shall be ensured:

- for blade length $l < 20$ m: 1 tip end receptor
- for blade length $20 \text{ m} \leq l < 30$ m: 1 tip end receptor and additionally 1 receptor on the pressure side and 1 receptor on the suction side (in a certain distance from the tip end)
- for blade length $30 \text{ m} \leq l < 45$ m: 1 tip end receptor and additionally 2 receptors on the pressure side and 2 receptors on the suction side (distributed over the rotor blade length)
- for blade length $l \geq 45$ m: 1 tip end receptor and additionally 3 receptors on the pressure side and 3 receptors on the suction side (distributed over the rotor blade length)

(5) The requirements of Section 8.9.3.1, para 4 do not have to be observed if the high-voltage strike attachment tests described in IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection”, Annex D.2 have been performed and show different requirements for the sufficient amount of receptors.

(6) The down-conductor system shall be built according to IEC 61400-24 "Wind turbine generator systems – Part 24: Lightning protection", subclause 8.2.4.2. The down conductor shall be insulated to reduce the risk of sparking.

(7) Cross-sectional areas of the air-termination system and the down-conductor system shall be dimensioned in accordance with IEC 62305-3 "Protection against lightning - Part 3: Physical damage to structures and life hazard", Table 6:

- for conductors of copper or aluminium alloys: at least 50 mm²

- for conductors of stainless steel tape: at least 50 mm with a minimum thickness of 2 mm
- for round conductors of stranded stainless steel: at least 70 mm² with a diameter of each strand of minimum 1.7 mm

(8) If the air-termination system or down-conductor system is placed on or integrated in the blade surface or if the blade surface itself is used as an air-termination system or down-conductor system (e.g. by using carbon fibre composites), then high-voltage and high-current testing shall be performed according to IEC 61400-24, Annex D. The testing shall prove the ability of the lightning protection system to attract the lightning flashes and to withstand the lightning current according to the assigned lightning protection level.

(9) The temperature rise of components in case of a lightning strike may not harm the integrity of the lightning protection system or the rotor blade itself. This shall be proven by calculations or laboratory testing.

(10) Rotor blades shall be fitted with drainage holes to minimize the danger of cracking caused by vaporization in case of a lightning strike.

8.9.3.2 Nacelle

(1) The nacelle structure shall be part of the lightning protection system and must be able to withstand lightning flashes according to the assigned lightning protection level.

(2) Metallic nacelle covers or metallic reinforcements shall be connected to the down-conductor system.

(3) Non-metallic nacelle covers shall be provided with an air termination system. The air termination system and the down conductors shall be connected to the down-conductor system.

(4) The air-termination system of non-metallic nacelle covers and of electrical instrumentation mounted outside the nacelle shall be designed according to IEC 62305-3 "Protection against lightning - Part 3: Physical damage to structures and life hazard", subclause 5.2 (air-termination systems) and connected to the down-conductor system.

(5) Cables connecting electrical instrumentation mounted outside the nacelle shall be routed through closed metallic conduits as long as they are routed outside the nacelle. These metallic conduits shall be connected to the down-conductor system.

(6) Alternatively to para 5, cables connecting electrical instrumentation mounted outside the nacelle may be designed according to IEC 62305-3 "Protection against lightning - Part 3: Physical damage to structures and life hazard", subclause 6.3 (Electrical insulation of the external LPS), provided no direct lightning strike is possible.

8.9.3.3 Spinner

In case of electrical installations and actuators mounted outside the hub and covered by the spinner, lightning protection of these components shall be provided. A typical measure is the placement of an air-termination system.

8.9.3.4 Tower

(1) Tubular steel towers are especially suited for lightning protection measures, because they can be considered to be an almost perfect Faraday cage. Thus it is reasonable to assign lightning protection zone LPZ 1 if SPDs are installed.

(2) The flanges of tubular steel towers between two tower sections shall be in direct electrical contact. The manufacturer shall describe the measures he has taken; verification shall be performed during witnessing of the commissioning or the IPE.

(3) Lattice towers shall not be considered to be efficient Faraday cages; they satisfy lightning protection zone LPZ 0_B.

(4) The structural elements of lattice towers may be used for lightning down conduction if these elements provide a cross-sectional area in compliance with IEC 62305-3 "Protection against lightning - Part 3: Physical damage to structures and life hazard", Table 6.

(5) The reinforcement of steel reinforced concrete towers may be used for lightning down conduction by ensuring 2 – 4 vertical connections with cross-sectional areas in compliance with IEC 62305-3 "Protection against lightning – Part 3: Physical damage to structures and life hazard", Table 6.

(6) It shall be noted in particular that, in case of a prestressed concrete tower or of a tower mounting using concrete-encased prestressed anchor bolts, these prestressing elements shall not be used for earthing purposes or lightning down conduction.

(7) The steel structure or the reinforcement of the tower, as applicable, shall be connected to the foundation or ring earth electrode by at least 3 points.

8.9.3.5 Bearings

(1) Bearings which are in the lightning current path, such as pitch, yaw, main bearings and gear, shall be protected as necessary to reduce the level of current passing through the bearing to a tolerable level.

(2) If the protection is part of the bearing structure itself, it shall be demonstrated that the bearing itself can operate for the whole design lifetime after being exposed to the expected number of lightning current penetrations. The bearing manufacturer must be involved in the demonstration and his final conclusion is required for A-Design Assessment.

(3) If the protection is not part of the bearing structure itself, an external protection system installed across the bearing shall bypass the lightning current.

Note :

It is strongly recommended that the lightning protection system be designed in such a way that the lightning current bypasses the bearings totally.

8.9.3.6 Hydraulic systems

Hydraulic systems exposed to lightning current shall be protected according to IEC 61400-24 "Wind turbine generator systems – Part 24: Lightning protection", subclause 8.4.3.

8.9.3.7 Bypass systems

(1) Spark gaps, sliding contacts, brushes, rollers and related technologies providing a bypass for bearings may function as the lightning protection of bearings. They shall be considered as wearing parts and their service lifetime and service measures must be documented.

(2) If the protection of bearings is to be achieved by spark gaps, sliding contacts, brushes, rollers or related technologies, the effectiveness of the bypass system shall be demonstrated by testing according to IEC 61400-24 "Wind turbine generator systems – Part 24: Lightning protection", subclause 8.4.5, or alternatively by calculations.

8.9.3.8 Connection of generator and gearbox

(1) Normally, the generator and the gearbox are satisfactorily linked to the earthing system through the connecting bolts with the main frame. However, if the gearbox or generator is connected to the main frame by means of flexible damping elements, all damping elements shall be bridged over with flat copper bands of sufficient cross-section.

(2) The coupling between gearbox and generator shall be insulated in such a way that the lightning current is not conducted via the generator shaft into the generator bearings.

(3) As gearbox bearings and other bearings are generally endangered by lightning currents, bypassing the main shaft completely is strongly recommended. This can be done by connecting the down conductor of the rotor blade to the earthing by other means than the main shaft, e.g. using sliding contacts or spark gaps outside the nacelle and tower. This necessitates insulation between the rotor blade roots and the main shaft.

8.9.3.9 Electrical systems and installations

Electrical systems and installations have to be protected against the effects of lightning current, overvoltage and lightning electromagnetic impulses (LEMP). This shall be done by means of equipotential bonding, magnetic and electrical shielding of cables and line routing, coordinated surge protection devices and earthing.

8.9.3.9.1 Surge arresters

(1) Surge arresters for low-voltage applications shall comply with

- IEC 61643-1 "Low-voltage surge protective devices – Part 1: Surge protective devices connected to low-voltage power distribution systems – Requirements and tests" for power systems
- IEC 61643-21 "Low-voltage surge protective devices- Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods" for telecommunication and signalling systems.

This shall be verified on the basis of product data sheets.

(2) The energy coordination of surge arresters shall be in compliance with IEC 62305-4 "Protection against lightning – Part 4: Electrical and electronic systems within structures", Annex C. Proof shall be given by testing, calculations or selection of coordinated surge arrester families. In each case, a description of the measures taken and the results achieved or protection levels achieved is required for assessment.

(3) Surge arresters for high-voltage or medium-voltage applications shall comply with

- IEC 60099-1 “Surge arresters – Part 1: Non-linear resistor type gapped surge arresters for a.c. systems” for gapped surge arresters
- IEC 60099-4 “Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems” for metal-oxide arresters

This shall be verified on the basis of product data sheets.

(4) The selection criteria for high-voltage and medium-voltage surge arresters shall be given and will be checked for plausibility.

(5) Surge arresters shall be monitored.

(6) Maintenance and replacement of surge arresters shall be performed according to the manufacturer’s maintenance plan, which is required for assessment.

8.9.3.9.2 Equipotential bonding system

(1) Equipotentialization shall be achieved by interconnecting the lightning protection system with

- structural metal parts
- metal installations
- internal systems
- external conductive parts and service lines connected to the structure

(2) The bonding conductors shall be kept as short as possible and shall have a cross-sectional area according to IEC 62305-3 “Protection against lightning - Part 3: Physical damage to structures and life hazard”, Tables 8 and 9.

(3) In each lightning protection zone, local bonding bars shall be installed and shall be connected to each other.

(4) Where possible, incoming cables should enter the lightning protection zone at the same location and be connected to the same bonding bar. If incoming cables enter the lightning protection zone at different locations, each cable shall be connected to a bonding bar and the respective bonding bars of the zone shall be connected (see IEC 62305-3 “Protection against lightning - Part 3: Physical damage to structures and life hazard”, subclause 5.4).

(5) The equipotential bonding system shall be assessed on the basis of an equipotential bonding plan for all bonding and earthing in the wind turbine, showing the general equipotential bonding system including the locations of the bonding bars within the different lightning protection zones, the bonding conductors with their cross-sectional areas as well as further relevant data.

8.9.3.9.3 Earthing system

(1) The earthing system of the wind turbine shall be designed to provide sufficient protection against damage due to lightning flashes corresponding to the lightning protection level for which the lightning protection system is designed.

(2) The earthing system shall be based on a type B arrangement according to IEC 62305-3 “Protection against lightning - Part 3: Physical damage to structures and life hazard”, subclause 5.4.2.2, which comprises either an external ring earth electrode in contact with the soil for at least 80 % of its total length or a foundation earth electrode.

(3) From the earth electrode, terminal lugs shall be routed into the inside of the tower and connected to the steel structure or reinforcement of the tower by at least 3 points (see subclause 8.9.3.4, para 7).

(4) Materials used for the earth electrodes of the wind turbine and the corresponding cross-sectional areas shall be in accordance with the values listed in IEC 62305-3 “Protection against lightning – Part 3: Physical damage to structures and life hazard”, Table 7.

(5) All transitions from the foundation earth electrode or the reinforcement out of the concrete into the air shall be executed with an insulated cable.

(6) Sufficient corrosion protection shall be applied for earthing cables, lugs, tapes and their connections to different materials. For inspection reasons, it shall be possible to locate and to disconnect each connection. Corresponding descriptions shall be submitted for GL assessment.

(7) From the earth electrode of the separate building, a connection shall be made to the earth electrode of the tower and to other earth electrodes of the site.

Note 1:

The complete lightning protection system, as well as the earthing system, is to be checked by an independent expert according to the scope laid down in IEC 61400-24 “Wind turbine generator systems – Part 24: Lightning protection”, Clause 12, as a visual inspection at yearly intervals and as a full inspection at intervals not exceeding 2 years.

Note 2:

A report by a local expert about the conformity of the earthing and lightning protection with the local rules shall be given with the wind turbine documentation to the user.

Appendix 8.A Generator Parameters for Electrical Calculations and Simulations

(1) Generator parameters are required for static and dynamic electrical calculations and simulations. The values shall be applied in accordance with the information supplied by the generator manufacturer. The tables below exemplify the main synchronous and asynchronous generator parameters.

(2) The synchronous machine parameters are:

Variable	**Description**	**Unit**
S_n	Rated power	kVA
M_n	Rated torque	kN
U_n	Rated voltage	V
P	Number of poles	-
f_n	Nominal frequency	Hz
x_l	Leakage reactance	p.u.
r_a	Armature resistance	p.u.
x_d	d-axis synchronous reactance	p.u.
x_d'	d-axis transient reactance	p.u.
x_d''	d-axis subtransient reactance	p.u.
T_{d0}'	d-axis open circuit transient time constant	s
T_{d0}''	d-axis open circuit subtransient time constant	s
x_q	q-axis synchronous reactance	p.u.
x_q'	q-axis transient reactance	p.u.
x_q''	q-axis subtransient reactance	p.u.
T_{q0}'	q-axis open circuit transient time constant	s
T_{q0}''	q-axis open circuit subtransient time constant	s
$T_a = 2H$	Mechanical starting time (2 x inertia constant)	kWs / kVA
D	Damping coefficient	-
S(1.0)*	1st saturation factor	-
S(1.2)*	2nd saturation factor	-

)* optional fields

The generator manufacturer shall indicate if the generator parameters given are of a saturated or non-saturated type.

(3) The asynchronous machine parameters are:

Variable	**Description**	**Unit**
S_n	Rated power	kVA
M_n	Rated torque	kNm
M_k	Breakdown torque	kNm
s_k	Breakdown slip	-
U_n	Rated voltage	V
f_n	Rated frequency	Hz
r_s	Stator resistance	p.u.
x_s	Stator reactance	p.u.
r_{r1}	Rotor resistance (single cage)	p.u.
x_{r1}	Rotor reactance (single cage)	p.u.
r_{r2}	Rotor resistance (double cage)	p.u.
x_{r2}	Rotor reactance (double cage)	p.u.
x_m	Magnetization reactance	p.u.
H_m	Inertia constant	kWs/kVA

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9 Manuals

Edition 2010

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9.1 Erection Manual

9.1.1 General

(1) The erection manual describes all working steps which have to be performed at the installation site during assembly, installation and erection of the wind turbine.

(2) The erection manual applies for one type of wind turbine, and if applicable for its variants.

(3) The erection report documents the execution of the individual working steps during the erection process. A blank form sheet of the erection report shall be added to the erection manual.

(4) For the instructions for the constructions of the foundation, please see Section 6.7.2.

9.1.2 Format of the erection manual

(1) The format and level of detail of the erection manual shall be such that the qualified technical erection personnel performing the required tasks are able to understand the instructions.

(2) For the issuance of the Project Certificate, the erection manual shall be expressed in a language which the qualified technical personnel at the installation site of the wind turbine are able to understand.

(3) IEC 62079 (Preparation of instructions – Structuring, content and presentation), especially section 5.9.3, shall be observed for the preparation of the erection manual in addition to this Guideline.

9.1.3 Scope of the erection manual

The erection manual shall contain the following information at least:

- type identification of the wind turbine (see Section 9.1.3.1)
- prerequisites for the erection
  (see Section 9.1.3.2)
- working steps of the erection process
  (see Section 9.1.3.3)
- warnings against hazardous situations
  (see Section 9.1.3.4)
- blank form sheets for the erection report
  (see Section 9.1.3.5)

9.1.3.1 Type identification of the wind turbine

At least the following information shall be provided:

- manufacturer, supplier, importer
- designation, type and if applicable type variant
- rotor diameter, hub height
- type of rotor blade
- rated power

9.1.3.2 Prerequisites for erection

(1) All prerequisites for the execution of the erection work shall be stated, e.g. requirements for the weather conditions (limiting wind speeds, temperatures, rainfall), requirements for site access and working area or adequate curing of the foundation.

(2) The precise designations and dimensions of all plant components to be assembled and erected shall be specified, together with all data needed for erection, such as weights, lifting points etc.

(3) Special tools or hoisting equipment necessary for the erection shall be specified considering the loads and weights during erection. Requirements for these tools or equipment e.g. testing or regular inspections shall be specified.

(4) The maximum admissible delay between erection of the tower and mounting of the nacelle shall be stated.

(5) The required qualifications for the technical erection personnel shall be defined in the erection manual.

9.1.3.3 Working steps for erection

(1) All working steps needed for erection shall be described. Auxiliary equipment and resources shall be specified exactly (e.g. lubricants, oil for filling up the gearbox).

(2) The erection manual shall refer to drawings, specifications or instructions necessary for the erection of the wind turbine.

(3) The work instructions as per Section 6.5.1, item b, for making the bolted connections needed during erection shall be added to the erection manual.

(4) All necessary tests and checks shall be listed.

(5) Procedures for energizing electrical equipment shall be provided.

9.1.3.4 Warnings against hazardous situations

(1) Hazardous situations which may arise through deviation from the planned erection sequence shall be named and countermeasures shall be specified. Such situations can include: lightning, snow, icing, visibility, very high winds during erection or prolonged periods of the tower standing without nacelle at critical wind speeds.

(2) Hazardous situations which may arise due to unintended motion or rotation shall be named, and countermeasures shall be specified to avoid this.

(3) Safety and accident-prevention measures which are necessary before or during assembly, installation and erection, e.g. use of personal protective equipment, guards or locking devices shall be specified.

(4) For personnel entering any enclosed working space such as the hub or blade interior, safety provisions shall be stated, e.g. standby personnel.

Note:

For the aspects of occupational safety, please refer to the note after Section 1.1.1, para 5.

9.1.3.5 Form sheet for the erection report

(1) The erection report shall document the execution of all checks and working steps of the erection process. For each check and working step, there shall be appropriate fields to be filled in, together with fields for recording measurement values and test results.

(2) All adjustment settings and set values as well as the expected measurement results shall be specified.

(3) The erection report may consist of several subreports (e.g. for different assemblies or phases of erection).

(4) The following fields shall be provided as a minimum:

- type identification of the wind turbine as per Section 9.1.3.1
- serial number, operator and installation site of the wind turbine
- name of the person carrying out the corresponding working step
- weather conditions, if the weather is able to influence the quality of work
- reports of the execution of all working steps
- reports of the execution of all tests and checks
- extra space for possible remarks or items outstanding
- date and signature of the person(s) responsible

9.2 Commissioning Manual

9.2.1 General

(1) The commissioning manual describes all working steps which have to be performed during commissioning in order to ensure safe functioning of the wind turbine.

(2) The commissioning manual applies for one type of wind turbine, and if applicable for its variants.

(3) The commissioning report documents the execution of the individual working steps during the commissioning process. A blank form sheet of the commissioning report shall be added to the commissioning manual.

9.2.2 Format of the commissioning manual

(1) The format and level of detail of the commissioning manual shall be such that qualified technical commissioning personnel performing the required tasks are able to understand the instructions.

(2) For the issuance of the Project Certificate, the commissioning manual shall be expressed in a language which the qualified technical personnel at the installation site of the wind turbine are able to understand.

(3) IEC 62079, especially section 5.9.4, shall be observed for the preparation of the commissioning instructions in addition to this Guideline.

9.2.3 Scope of the commissioning manual

The commissioning manual shall contain the following information as a minimum:

- type identification of the wind turbine (see Section 9.2.3.1)
- checks required before the start of commissioning (see Section 9.2.3.2)
- working steps of the commissioning process (see Section 9.2.3.3)
- checks required to conclude the commissioning (see Section 9.2.3.4)
- warnings against hazardous situations (see Section 9.2.3.5)
- blank form sheets for the commissioning report (see Section 9.2.3.6)

9.2.3.1 Type identification of the wind turbine

At least the following information shall be provided:

- manufacturer, supplier, importer
- designation, type and if applicable type variant
- rotor diameter, hub height
- type of rotor blade
- rated power

9.2.3.2 Checks before commissioning

(1) All checks required before the start of commissioning shall be listed. The following statements shall be provided as a minimum:

- erection and assembly – completed to full extent
- commissioning of the auxiliary systems and subsequent external equipment needed for operation of the wind turbine (e.g. transformer, grid connection station) – completed
- any trial runs of individual components which may be necessary in the factory or on site – completed
- filling up of all operating media (e.g. lubricants, coolants, hydraulic fluid, nitrogen in pressure tanks) – completed
- any acceptance tests needed according to governmental regulations (e.g. for pressure vessels, lifts) – completed

(2) The required qualifications for the technical commissioning personnel shall be defined in the commissioning manual.

9.2.3.3 Working steps for commissioning

(1) All working steps needed for commissioning shall be described. For the commissioning of individual assemblies (e.g. yaw system), reference may be made to subordinate commissioning manuals for such assemblies.

(2) All prerequisites for the proper execution of commissioning, e.g. lowest/highest wind speed and necessary outside temperatures, shall be specified.

(3) Tests of all functions of the safety systems and the braking systems shall be described. The switching values to be set and criteria to be met shall be specified. The following tests shall be performed as a minimum:

- function of all emergency stop pushbuttons
- function of all sensors and switches which also act on the safety system (e.g. overspeed test)
- measurement of the essential parameters of the braking systems, e.g. speed of blade pitching, hydraulic pressure of the mechanical brake(s)
- response of all necessary plant functions after activation of the safety system (e.g. braking systems, generator disconnection)
- test to verify that the functions responding to the activation of the safety system are independent of the control system
- grid loss
- testing of all limiting values and parameters that have been set for the safety system

(4) All tests regarding the functions of the control system of the wind turbine shall be described. The switching values to be set and criteria to be met shall be specified. The following tests shall be performed as a minimum:

- automatic start-up
- shut-down with all braking procedures
- plausibility check of the yaw system
- plausibility check of the measurement values
- comparison of the limiting values and parameters which were set with the prescribed values as documented

(5) Furthermore, the following working steps shall be described:

- registration of the data on the rating plates of the primary components
- possible settings to be made in the control system on the basis of the measurement results (e.g. natural frequency of the tower)
- familiarization of the wind turbine operating personnel

9.2.3.4 Checks to conclude commissioning

All checks required to conclude commissioning shall be listed. The following statements shall be provided as a minimum:

- visual inspections (e.g. rotor blades, corrosion protection, tightness of hydraulic system)
- checking of the required notices and warning plates

9.2.3.5 Warnings against hazardous situations

(1) Hazardous situations which may arise during commissioning shall be named and countermeasures shall be specified. Such situations can include: grid loss, lightning, icing or very high winds during commissioning.

(2) Hazardous situations which may arise due to unintended motion or rotation shall be named, and countermeasures shall be specified to avoid this.

(3) Safety and accident-prevention measures which are necessary before or during commissioning, e.g. use of personal protective equipment, guards or locking devices shall be specified.

(4) For personnel entering any enclosed working space such as the hub or blade interior, safety provisions shall be stated, e.g. standby personnel.

Note:

For the aspects of occupational safety, please refer to the note after Section 1.1.1, para 5.

9.2.3.6 Form sheet for the commissioning report

(1) The commissioning report shall document the execution of all checks and working steps of the commissioning process. For each check and working step, there shall be appropriate fields to be filled in, together with fields for recording the measurement values and test results.

(2) All adjustment settings and set values as well as the expected measurement results shall be specified.

(3) The commissioning report may consist of several sub-reports (e.g. for primary components, for familiarization of the operating personnel, …).

(4) The following fields shall be provided as a minimum:

- type identification of the wind turbine as per Section 9.2.3.1
- serial number, operator and installation site of the wind turbine
- manufacturer, type and serial number from the rating plates of the primary components, at least of the rotor blades, gearbox, generator and tower
- persons present during commissioning

- weather conditions on the day of commissioning
- confirmation that all checks required before the start of commissioning as per Section 9.2.3.2 have been completed
- report on the execution of all working steps of the commissioning as per Section 9.2.3.3
- confirmation that all checks required to conclude commissioning as per Section 9.2.3.4 have been completed
- extra space for possible remarks, items outstanding or parts replaced
- date and signature of the person(s) responsible

9.3 Operating Manual

9.3.1 General

(1) The operating manual is intended to provide the operator or his representative with the knowledge necessary for proper operation of the wind turbine.

(2) The operating manual applies for one type of wind turbine, and if applicable for its variants.

9.3.2 Format of the operating manual

(1) The format and level of detail of the operating manual shall be such that qualified personnel with technical training are able to understand the instructions.

(2) For the issuance of the Project Certificate, the operating manual shall be expressed in a language which the qualified personnel at the installation site of the wind turbine are able to understand.

(3) IEC 62079, especially section 5.10, shall be observed for the preparation of the operating instructions in addition to this Guideline.

9.3.3 Scope of the operating manual

The operating manual shall contain the following information:

- type identification of the wind turbine
  (see Section 9.3.3.1)
- notes for users
  (see Section 9.3.3.2)
- warnings against hazardous situations
  (see Section 9.3.3.3)
- help with fault-finding
  (see Section 9.3.3.4)
- operating records
  (see Section 9.3.3.5)

9.3.3.1 Type identification of the wind turbine

At least the following information shall be provided:

- manufacturer, supplier, importer
- designation, type and if applicable type variant
- rotor diameter, hub height
- type of rotor blade
- rated power

9.3.3.2 Notes for users

At least the following information shall be provided:

- general description of the operation concept
- description of the functions and operational modes of all the operating and indicating elements (switches, pushbuttons, lamps, measuring instruments)
- description of starting and stopping procedures
- description of emergency shut-down
- explanation of fault messages (insofar as these are issued)
- description of all work procedures required for the operating of the wind turbine (e.g. necessary communication)
- emergency procedure plans, e.g. action required in the event of overspeeding, ice formation, lightning storms, earthquakes, brake failure, rotor imbalance, loose fasteners or fire at the wind turbine

9.3.3.3 Warnings against hazardous situations

(1) Hazardous situations which may arise when operating the wind turbine on site shall be named and countermeasures shall be specified. Such situations can include fire, lightning, ice formation and very high winds.

(2) Hazardous situations which may arise due to unintended motion or rotation shall be named and countermeasures (e.g. emergency procedure plans) shall be specified to avoid this.

(3) Safety and accident-prevention regulations, e.g. use of personal protective equipment, guards or locking devices shall be specified.

Note:

For the aspects of occupational safety, please refer to the note after Section 1.1.1, para 5.

9.3.3.4 Help with fault-finding

Without carrying out any repairs himself, the operator should be capable of recognizing the cause of a malfunction and – insofar as it cannot be cleared simply by an operating action – of providing the qualified technical maintenance personnel with useful advance information.

The operator should be able to judge whether a fault constitutes or can develop into a hazardous situation (see Section 9.3.3.3).

9.3.3.5 Operating records

Operating records shall be kept and shall include the following:

- type identification of the wind turbine (see Section 9.3.3.1)
- serial number, operator and installation site of the wind turbine
- operating hours
- shut-down hours
- date and time of fault
- nature of fault
- date and time of maintenance or repair activity
- nature of maintenance or repair activity

9.4 Maintenance Manual

9.4.1 General

(1) The maintenance manual describes all working steps which have to be performed during maintenance in order to ensure safe functioning of the wind turbine; this includes supervising actions, reconditioning, repairing, adjusting and cleaning.

(2) The maintenance manual applies for one type of wind turbine, and if applicable for its variants.

(3) The maintenance record documents the execution of the individual working steps during the maintenance process. A blank form sheet of the maintenance record shall be added to the maintenance manual.

(4) The maintenance shall be carried out by qualified technical maintenance personnel.

9.4.2 Format of the maintenance manual

(1) The format and level of detail of the maintenance manual shall be such that the qualified technical maintenance personnel performing the required tasks are able to understand the instructions.

(2) For the issuance of the Project Certificate, the maintenance manuals shall be expressed in a language which the qualified technical personnel at the installation site of the wind turbine are able to understand.

(3) IEC 62079, especially section 5.11 to 5.14, shall be observed for the preparation of the maintenance manuals in addition to this Guideline.

9.4.3 Scope of the maintenance manual

The maintenance manual shall contain the following information at least:

- type identification of the wind turbine
  (see Section 9.4.3.1)
- prerequisites for the maintenance
  (see Section 9.4.3.2)
- working steps of the maintenance
  (see Section 9.4.3.3)
- warnings against hazardous situations
  (see Section 9.4.3.4)
- blank form sheets for the maintenance report
  (see Section 9.4.3.5)

9.4.3.1 Type identification of the wind turbine

At least the following information shall be provided:

- manufacturer, supplier, importer
- designation, type and if applicable type variant
- rotor diameter, hub height
- type of rotor blade
- rated power

9.4.3.2 Prerequisites for maintenance

(1) All prerequisites for the execution of the maintenance work shall be stated, e.g. requirements for the weather conditions (wind, temperatures).

(2) Special tools or lifting devices necessary for the maintenance shall be specified.

(3) Technical documentation of the wind turbine and their subsystems including e.g. wiring diagrams, hydraulic schemes or lubrication charts.

(4) The required qualifications for the technical maintenance personnel shall be defined in the maintenance manual.

9.4.3.3 Working steps for maintenance

(1) All working steps needed for maintenance or inspections shall be described. The descriptions may be supplemented by appropriate pictorial representations. The objectives of the individual maintenance operations (oil levels, brake settings, oil pressures etc.) shall be indicated clearly.

(2) The frequency of the schedule maintenance (e.g. half-yearly, yearly or five-yearly) shall be specified.

(3) A set of work instructions as per Section 6.5.3 for the inspection of bolted connections shall be added to the maintenance manual.

(4) A detailed listing and description of the necessary tests for the safety system (e.g. overspeed test, emergency shut-down functions, measurement of the nitrogen content in hydraulic accumulators) shall be included in the maintenance record. The required frequency of these tests shall be indicated (e.g. annually). The completion of the tests shall be recorded in the maintenance report.

(5) If applicable, the investigations of technical experts and authorized persons, as required by the relevant national regulations (e.g. for lifts, fire-extinguishing systems and pressure vessels) and conditions of the building permits, shall be included in the maintenance manual, and columns/sections shall be provided in the maintenance report for the confirmation that these investigations have been carried out.

(6) All components and auxiliary materials of the wind turbine that have to be exchanged according to schedule during the operating life (e.g. hydraulic hoses, brake pads, sliprings, gear oil) shall be listed. The intervals or criteria for the exchange shall be specified.

(7) In addition, information shall be given about the quality and quantity of spare parts and auxiliary materials to be used, e.g. lubricants (spare parts list).

9.4.3.4 Warnings against hazardous situations

(1) Hazardous situations which may arise during maintenance shall be named and countermeasures shall be specified. Such situations can include fire, lightning, icing and very high winds.

(2) Hazardous situations which may arise due to unintended motion or rotation shall be named and countermeasures shall be specified to avoid this.

(3) Safety and accident-prevention measures which are necessary before or during maintenance, e.g. use of personal protective equipment, guards or locking devices shall be specified.

(4) For personnel entering any enclosed working space such as the hub or blade interior, safety provisions shall be stated, e.g. standby personnel.

Note:

For the aspects of occupational safety, please refer to the note after Section 1.1.1, para 5.

9.4.3.5 Form sheet for the maintenance report

(1) The maintenance report shall document the execution of all checks and working steps of the maintenance process. For each check and working step, there shall be appropriate fields to be filled in, together with fields for recording measurement values and test results.

(2) All adjustment settings and set values as well as the expected measurement results shall be specified.

(3) The maintenance report may consist of several sub-reports (e.g. for primary components such as rotor blades or tower).

(4) The following fields shall be provided as a minimum:

- type identification of the wind turbine as per Section 9.4.3.1
- serial number, operator and installation site of the wind turbine
- persons present during maintenance
- weather conditions on the day of maintenance
- operating hours
- shut-down hours
- report on the execution of all working steps of the maintenance as per Section 9.4.3.3
- confirmation that all checks required to conclude maintenance have been completed
- parts replaced
- extra space for possible remarks or items outstanding
- date and signature of the person(s) responsible

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1 Guideline for the Certification of Wind Turbines

10 Testing of Wind Turbines

Edition 2010

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10.1 General

10.1.1 Prototype test

10.1.1.1 General requirements

(1) The measurements needed for a new turbine type within the scope of a prototype test are listed in Sections 10.2 to 10.7. The scope of the prototype test can be reduced for turbine variants or modified turbines after consultation with GL, provided that the prototype test was performed in its entirety for a predecessor turbine.

(2) The measurement points, the planned scope of the measurements and their assessment shall be coordinated with GL before installation of the measurement equipment commences.

(3) All measurements as per Sections 10.2 to 10.6 and 10.7.3 shall be carried out and documented by a test institute accredited for these measurements. Alternatively, the test of the turbine behaviour as per Section 10.5, the load measurements as per Section 10.6 and the prototype test of the gearbox at the wind turbine as per Section 10.7.3 can be carried out by the manufacturer after prior consultation with GL, and then checked and witnessed by a test institute accredited for these measurements. In all cases, the accredited institute shall be responsible for compliance with the fundamental standards and with the requirements of this Guideline. The influence of a turbine variant on the measurement result shall be assessed by the accredited institute which performed the measurements on the original installation.

(4) The gearbox prototype test at the wind turbine as per Section 10.7.3 forms part of the prototype test.

(5) On completion of the measurements, the following activities shall be performed:

- evaluation and documentation of the measurements
- plausibility check of the measurement results
- comparison of the measurement results with the assumptions in the design documentation

10.1.1.2 Requirements for the wind turbine to be tested

(1) The wind turbines at which the measurements as per Sections 10.2 to 10.6 and 10.7.3 are carried out shall conform to the greatest possible extent to the design on which the Design Assessment is based. Compliance shall be confirmed in a declaration by the manufacturer. Any deviations shall be reported to GL. If the compliance is adequate for the corresponding test purpose, the measurement can be used for the certification.

(2) The test institute performing the measurements shall record the designations and data on the rating plates of the surveyed plant and on the rating plates of the primary components (at least the rotor blades, gearbox, generator and tower) and shall include them in the measurement report.

10.1.2 Tests within the scope of the Design Assessment

(1) No tests are required within the scope of D-Design Assessment and C-Design Assessment; only the static rotor blade test is recommended (see para 2).

(2) Blade tests as per Section 6.2.5 are required as part of the assessment of the rotor blade as follows:

- Within the scope of the C-Design Assessment, it is not required but strongly recommended that the static rotor blade test be performed.
- Within the scope of the B-Design Assessment, the static rotor blade test shall be performed successfully. The test report and the evaluation of the test may be presented later and will be listed as outstanding items.
- Within the scope of the A-Design Assessment, the static rotor blade test shall be performed successfully. The test report and the evaluation of the test shall be submitted to and accepted by GL.

(3) The prototype test of the main gearbox at the test bench as per Section 10.7 shall be completed before the A-Design Assessment is issued; see Section 10.7.1. Under certain circumstances, the test at the test bench may already be necessary for the B-Design Assessment; see Section 10.7.1.

(4) The prototype test of the generator frequency converter system shall be completed before issuance of the A-Design Assessment (see Section 8.2.2, para 5, 8.2.6, para 1, 8.4.5, para 7 and 8.2.8, para 1 through 5).

These are several tests which can all be performed together:

- generator: thermal performance test (temperature rise)
- generator: other performance tests (withstand voltage test, over speed, THD) and short-circuit resistance
- frequency converter: temperature rise test
- maximum voltage steepness during normal operation
- blocked blower test
- current and voltage measurements between generator and frequency converter
- shaft current and voltage measurement (shaft to housing)

Additional test for the frequency converter: vibration test according to IEC 60721-3-3 for climatic class 3M4.

(5) Transformer testing shall contain all tests given in Section 8.3, as listed below. They need to be completed for A-Design Assessment, and test reports shall be submitted for assessment.

- temperature rise test
- dielectric type tests
- lightning impulse test

(6) All prototype tests with the main power frequency converter as described in Section 8.4.5 need to be completed for A-Design Assessment, and reports shall be submitted for assessment. These are

- protective bonding impedance test
- impulse withstand voltage test
- temporary overvoltage test
- protective bonding impedance, type test (exception when total enclosed)
- touch current measurement
- AC or DC voltage test
- partial discharge test
- temperature rise test including voltage steepness
- hydrostatic pressure test and loss of coolant test (except for air cooling)
- vibration test, according to Section 8.4.5, para 11

(7) The following prototype tests of medium-voltage switchgear through need to be completed for A-Design Assessment, for C-Design Assessment; the test reports shall be submitted for assessment, as detailed in Section 8.5.

- dielectric tests
- short-time withstand current test
- peak withstand current test
- arc resistance test

(8) For lightning protection assessment, the following tests need to be completed for A-Design Assessment, and reports shall be submitted for assessment:

- high-voltage and high-current tests, if required in Section 8.9.3.1, para 1 or para 9
- mechanical testing of air-termination and down-conductor system within the testing according to Section 10.1.2, para 2

(9) Within the scope of the Design Assessment, witnessing of the commissioning at one of the first installations of the type is also required as per Section 10.8. This witnessing shall be completed before the A-Design Assessment is issued.

(10) The tests and inspection of the load-relevant control and safety system functions (LRF) according to Sections 4.5.4.3 and 4.5.4.4 shall be completed before the A-Design Assessment is issued. An exception to this is stated as per Section 4.5.4.3, para 5.

10.2 Power Curve

(1) Measurement of the power performance of the wind turbine shall be carried out in accordance with IEC 61400-12-1 “Wind turbine generator systems – Part 12: Wind turbine power performance testing” or DIN EN 61400-12-1, in each case as the latest version.

(2) Deviations from this standard shall be justified and defined in consultation with GL. Furthermore, the deviations shall be listed in detail within a separate chapter in the test report.

(3) On completion of the measurements, the measured power curve shall be compared by the test institute or by the wind turbine manufacturer with the power curve assumed in the design documentation. Here special attention shall be paid to sufficient correspondence with the assumed values for rated wind speed and rated power, for which site-specific orographical and meteorological conditions may have to be taken into consideration.

(4) Generally, mandatory measurements shall be agreed with GL when introducing any variants of the wind turbine. However, when introducing a new rotor blade type, rotor diameter or a new rated rotational speed, new measurements shall be carried out as a rule.

(5) The measurement report of the accredited test institute and the comparison with the assumptions (see Section 10.1.1.1, para 5) shall be submitted to GL for assessment.

10.3 Noise Emission

(1) Measurement of the noise emissions of the wind turbine shall be carried out in accordance with IEC 61400-11 “Wind turbine generator systems – Part 11: Acoustic noise measurement techniques” or DIN EN 61400-11, in each case as the latest version.

(2) Deviations from this standard shall be justified and defined in consultation with GL. Furthermore, the deviations shall be listed in detail within a separate chapter in the test report.

(3) Generally, mandatory measurements shall be agreed with GL when introducing any variants of the wind turbine. However, when introducing a new rotor blade type (e.g. other aerodynamic surface), rated rotational speed, tower design (lattice/tubular/hybrid), type of gearbox or major changes in the electrical installations (e.g. grid frequency), new measurements shall be carried out as a rule.

(4) The measurement report of the accredited test institute shall be submitted to GL for evaluation.

10.4 Electrical Characteristics

(1) Measurement of the electrical characteristics of the wind turbine shall be carried out in accordance with IEC 61400-21 “Wind turbine generator systems – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines”, Edition 2. The measurements according to the subclauses 6.5 to 6.9 of the above-mentioned IEC document are optional.

(2) Deviations from this standard shall be justified and defined in consultation with GL.

(3) It shall be observed that a renewed measurement of the electrical characteristics is necessary as a rule whenever the generator type, any existing power electronic device in the main power circuit, relevant parts in its controller software, or the grid frequency is changed or when a new blade design is introduced.

(4) The changes in the controller software of any power electronic device in the main power circuit shall be described and submitted for GL assessment. This description shall contain the software designation, release number, implementation date and an evaluation of the relevance concerning electrical characteristics.

(5) The report of the accredited test institute shall be submitted to GL for evaluation.

Note:

If load case DLC 9.2 (see Section 4.3.3.9, para 2) is considered, the measurements of the electrical characteristics shall reflect the details assumed when defining this design load case (e.g. low-voltage ride-through scenario).

10.5 Test of Turbine Behaviour

10.5.1 General

(1) The test of turbine behaviour is intended to verify the parameters and characteristics used as the basis for the design of the wind turbine.

(2) The test of turbine behaviour comprises the following individual tests:

- test of the safety system (Section 10.5.3)
- test of the braking systems (Section 10.5.4)
- test of automatic operation (Section 10.5.5)
- test of the switching operations (Section 10.5.6)
- measurement of the natural frequencies (Section 10.5.7)

(3) The tests shall preferably be carried out at the wind turbine fitted with instrumentation for load measurements as per Section 10.6.

(4) The requirements of IEC TS 61 400 – 13 “Wind turbine generator systems – Part 13: Measurement of mechanical loads” shall be applied with the necessary changes to the areas of

- calibration
- requirements for the measurement parameters and the measurement system
- reporting

(5) The test of turbine behaviour shall be carried out by a test institute accredited for load measurements at wind turbines, or shall be verified and witnessed by such an institute (see Section 10.1.1).

(6) Generally, renewed tests of turbine behaviour are necessary when renewed load measurements are required. In the case of type variants, the scope of measurements may be reduced in consultation with GL to those measurement parameters which are influenced by the design modifications.

(7) The measurement report and the verification by the accredited test institute (if applicable) and the comparison with the assumptions (see Section 10.1.1.1, para 5) shall be submitted to GL for assessment.

10.5.2 Test plan

Before the start of the tests, a test plan shall be submitted to GL for consultation. The test plan shall contain at least the following information:

- measurement parameters
- extent of the measurements and a precise description of the test, stating the resolution of the measurement data
- envisaged evaluations

10.5.3 Test of the safety system

(1) For these tests, at least the following measurement parameters shall be recorded:

- wind speed
- rotational speed
- electrical power output
- blade angle or position of the aerodynamic brakes (if applicable)
- hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)
- torque of the main shaft or driving torque of the rotor
- blade root bending moments

(2) The tests set out in Table 10.5.1 shall be performed.

Table 10.5.1 Tests of the safety system

No.	Test	Number of tests for wind speed < 80 % of V_r	Number of tests for wind speed ≥ 80 % of V_r	Remarks
10.5.3.1	Activation of the brakes through exceeding of n_A	-	2	
10.5.3.2	Activation of brakes through actuation of an emergency off pushbutton	2		Activation during power production

10.5.4 Test of the braking systems

(1) For these tests, at least the following measurement parameters shall be recorded:

- wind speed
- rotational speed
- electrical power output
- blade angle or position of the aerodynamic brakes (if applicable)
- hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)
- torque of the main shaft or driving torque of the rotor
- blade root bending moments

Note:

It is very useful to measure the rotational speed of the main shaft, gearbox output and generator.

(2) After braking of the wind turbine, recording of the measurements shall continue (during the idling condition or at standstill of the turbine) until a steady-state condition has been reached.

(3) The tests set out in Table 10.5.2 shall be performed.

Table 10.5.2 Tests of the braking systems

No.	Test	Number of tests for wind speed < 80 % of V_r	Number of tests for wind speed ≥ 80 % of V_r	Remarks
10.5.4.1	Braking with failure of one aerodynamic braking system	2	2 4)	For wind turbines with more than one aerodynamic braking system 1), 4)
10.5.4.2	Braking with failure of braking system I	2	2	For wind turbines with exactly two braking systems
10.5.4.3	Braking with failure of braking system II	2	2	

Table 10.5.2 Tests of the braking systems (continued)

No.	Test	Number of tests for wind speed < 80 % of V_r	Number of tests for wind speed ≥ 80 % of V_r	Remarks
10.5.4.4	Braking with other assumable malfunctions in the braking systems	2 Tests for each assumable malfunction (wind speeds to be defined realistically)		2)
10.5.4.5	Effectiveness of the mechanical brake(s)	2		3)

Remark 1): The blade root bending moments shall be measured at one of the blades with and at the blade without blade pitching function. If only one blade is fitted with instrumentation, the number of tests shall be doubled in each wind speed range, whereby the failure of the aerodynamic braking system shall be tested at the instrumented blade and then at another.

Remark 2): These tests may be necessary if other malfunctions have been assumed in the consideration of possible faults as per Section 2.1.3 (e.g. failure of the blade pitching motor to switch off when feathering).

Remark 3): The magnitude of the braking moment and the build-up curve of the braking moment shall be shown by means of a suitable test.

Remark 4): For wind turbines with full-span pitch control, the tests for wind speed ≥ 80 % of V_r may be omitted after consultation with GL.

10.5.5 Test of automatic operation

(1) For these tests, at least the following measurement parameters shall be recorded:

- wind speed
- rotational speed
- electrical power output
- blade angle or position of the aerodynamic brakes (if applicable)
- hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)
- torque of the main shaft or driving torque of the rotor
- blade root bending moments

Note:

It is very useful to measure the rotational speed of the main shaft, gearbox output and generator.

(2) The tests set out in Table 10.5.3 shall be performed.

Table 10.5.3 Tests of automatic operation

No.	Test	Number of tests for wind speed < V_r	Number of tests for wind speed ≥ V_r	Remarks
10.5.5.1	Automatic operation	2	2	Duration of the test: approx. 2 minutes
10.5.5.2	Reference is made to the tests and inspections of the load-relevant control and safety system functions (LRF) according to Sections 4.5.4.3 and 4.5.4.4. Outstanding items shall be submitted together with the results of these measurements, by the latest.			

10.5.6 Test of the switching operations

(1) For these tests, at least the following measurement parameters shall be recorded:

- wind speed
- wind direction at the wind measurement mast (for the test of yaw control)
- nacelle position (for the test of yaw control)
- rotational speed
- electrical power output
- blade angle or position of the aerodynamic brakes (if applicable)
- hydraulic pressure at the mechanical brake(s) (see Section 10.5.8)
- torque of the main shaft or driving torque of the rotor
- blade root bending moments

Note:

It is very useful to measure the rotational speed of the main shaft, gearbox output and generator.

(2) After the switching operation, the recording of the measurements shall continue until a steady-state condition has been reached.

(3) The tests set out in Table 10.5.4 shall be performed.

Table 10.5.4 Tests of the switching operations

No.	Test	Number of tests for wind speed < 80 % of V_r	Number of tests for wind speed ≥ 80 % of V_r	Remarks
10.5.6.1	Start-up of the turbine	2	2	
10.5.6.2	Shut-down with all defined braking procedures	2 tests per braking procedure		1)
10.5.6.3	Switch-over of the generator-grid connection	2 switch-overs in either direction		For wind turbines with 2 or more fixed speeds and/or star-delta connection
10.5.6.4	Braking in the case of grid failure or load shedding	2	2	
10.5.6.5	Activation of the yaw system		1 yaw operation in either direction	
Remark 1):	For wind turbines with blade pitch control, the blade pitching rates shall be documented in the report.			

10.5.7 Measurement of the natural frequencies

(1) For these tests, the measurement parameters that are appropriate in each case shall be recorded and evaluated. The natural frequencies shall be determined by counting of vibration cycles or by frequency analyses of suitable measurement signals.

(2) The natural frequencies shall be determined as per Table 10.5.5.

(3) If a vibration damper system is fitted in the tower, the natural frequencies for the tower shall be determined in the directions of movement damped by the system both with and without the vibration damper system functioning.

10.5.8 Hydraulic pressure at the mechanical brakes

(1) As an alternative to measurement of the hydraulic pressure, an alternative measurement parameter can be recorded if the signal exhibits a clear relationship to the applied braking moment (e.g. position of a control valve). This relationship shall be documented in the measurement report.

(2) In the case of brakes that are activated at fixed levels (e.g. hard braking / soft braking / off), simple logging of the brake status shall suffice. The status signal shall be sensed at the brake or at the hydraulic system. The pressures or the braking moments of the individual levels shall be documented in the report.

Table 10.5.5 Measurement of the natural frequencies

No.	Component	Standstill	Production
10.5.7.1	Rotor blade	– 1st and 2nd natural mode, flapwise – 1st and 2nd natural mode, edgewise	– 1st and 2nd natural mode, flapwise – 1st and 2nd natural mode, edgewise
10.5.7.2	Drive train	1st natural mode for torsion with generator switched off and mechanical brake opened (excitation e.g. through closing and opening of the mechanical brake)	1st natural mode for torsion with generator switched on
10.5.7.3	Tower	– 1st natural mode for bending in direction XK 1),2) – 1st natural mode for bending in direction YK 1),2) – 2nd natural mode for bending – 1st natural mode for torsion, except for torsionally stiff towers	– 1st natural mode for bending in direction XK 2) – 1st natural mode for bending in direction YK 2)

Note *1): The rotor position shall preferably be so selected that one blade points vertically downward.*

Remark 2): XK and YK as per coordinate system in Appendix 4.A, Section 4.A.5

10.6 Load Measurements

(1) Load measurements shall be carried out in accordance with IEC TS 61 400 – 13 “Wind turbine generator systems – Part 13: Measurement of mechanical loads”, as the latest version.

(2) The measurement report of the accredited test institute shall be submitted to GL for assessment.

(3) Before the measurements are conducted, the measurement parameter plan and the extent of the measurements shall be agreed with GL as far as possible. According to IEC TS 61400-13 measurements shall be classified in two ways: steady state operation and transient events.

(4) At least following steady state operation cases shall be measured as defined in IEC TS 61400-13:

- power production
- power production with occurrence of fault
- parked and/or idling

(5) At least following transient events shall be measured as defined in IEC TS 61400-13:

- start up
- normal shut down
- emergency shut down
- grid failure

(6) In contrary to IEC TS 61400-13 the measurements of the steady operation cases listed in para 4 and transient events listed in para 5 are not a recommendation but a requirement of GL Guideline. Deviations from the technical specification shall be defined in consultation with GL. Furthermore, the deviations shall be listed in detail within a separate chapter in the test report.

(7) Measured meteorological quantities shall include wind speed at hub, wind shear, wind direction, air temperature, temperature gradient and air density.

(8) After completion of the measurements a load calculation shall be carried out. For the load calculation the simulation model used for achieving the load assumption certified with the A-Design Assessment shall be applied. With this model measured load cases shall be simulated taking into account the wind condition as documented in the measurement. In the simulation, both fatigue and extreme loads shall be investigated.

(9) In order to have comparable wind conditions the measured wind data sets shall be analysed with respect to mean value, standard deviation, trends (wind speed and direction) and wind direction changes. These shall be applied for simulation respectively. The measured turbulent wind speed autospectral density shell be analysed and compared to the spectral formulation used for load analysis.

(10) Fatigue load analysis: Only power production (DLC 1.1) load cases shall be considered. The DLC 1.1 shall be investigated applying two different turbulences as measured with the capture matrix as defined in IEC TS 61400-13. As result two dimensional load spectra shall be evaluated at the cross sections as measured in compliance with IEC TS 61400-13. Additionally the load duration distribution (LDD) of the shaft torque shall be evaluated. The load spectras and LDD shall be compared with the evaluations of respective measured datasets.

Note:

The capture matrix for fatigue analysis is defined in IEC TS 61400-13, table 3,

(11) Ultimate load analysis shall consider:

- at least two sets of DLC 1.1 considering two different turbulence intensities according to measured capture matrix
- transient loads as defined in section 10.5
- Idling at wind speed up to rated wind speed plus 2m/s shall be investigated.

The statistics of the measured and calculated loads shall be compared. The time series of measurement and simulation considering loads as well as all parameters defining the turbine status and operation mode, shall be compared.

(12) Results of comparison are to be discussed and justified. The measurements shall show that under consideration of technical tolerances assumptions made for design were conservative. In case of significant deviations, corrective measures shall be taken (i.e. redesign of affected structure).

(13) The load analysis report shall in general comply with requirements as stated in chapter 4 with respect to the documentation required.

(14) Generally, mandatory measurements shall be agreed with GL, when introducing any variants of the wind turbine. However, when introducing a new rotor blade type, rated rotational speed, tower type (lattice/tubular/hybrid) new measurements shall as a rule be carried out.

Note:

Applicability of existing measurements shall be shown by simulation

10.7 Prototype Tests of Gearboxes

10.7.1 General

(1) Gearbox types intended for installation in the drive train of wind turbines (main gearbox) shall be subjected to a prototype test at a suitable test bench and also to a prototype test at the wind turbine for which this gearbox was developed. The prototype test at the test bench serves to check the assumptions made in the design of the gearbox and also to obtain important parameters for the execution of series tests during the production of wind turbine gearboxes. The fundamental suitability of the gearbox for use in the wind turbine shall be verified through a prototype test at the wind turbine by measuring the bearing temperatures, sound and/or vibration behaviour and inspecting the gear contact patterns.

(2) In the event of design modifications (e.g. alteration of the gear ratio) which exert an appreciable effect on the dynamic characteristics of the gearbox or on the load distribution for individual components of the gearbox, a renewed prototype test is necessary. The corresponding scope shall be determined in relation to the design modification and in consultation with GL.

(3) Before the A-Design Assessment is issued, the prototype test at the test bench shall have been completed and documented. The test plan shall be assessed by GL prior to the prototype test. The prototype test at the test bench and the subsequent inspection of the disassembled gearbox shall be assessed by GL.

(4) If major results of the prototype test have already been incorporated into the calculations of the gearbox according to Section 7.4, completion of the gearbox test at the test bench may already be required for the B-Design Assessment.

(5) Before a Type Certificate is issued, the prototype test at the wind turbine shall have been completed and documented. The test plan shall be assessed by GL prior to the prototype test at the wind turbine.

(6) The detailed scope of the prototype tests shall be specified in consultation with GL before the tests commence.

10.7.2 Scope of the prototype test at the test bench

The following items at least shall be observed before and during the test of wind turbine gearboxes at the test bench:

- The gearbox under test and its essential components shall be uniquely identifiable. The relevant quality documents shall be made available by the time of the test.
- The prototype test at the test bench shall also include the function of the cooling system and the lubrication system. A realistic test bench set-up and the simulation of extreme operating conditions shall be provided.
- The purity of the lubricant used shall be ensured and monitored before and constantly during the test at the test bench. The cleanliness limit stated in Section 7.3.5.4, para 6 shall be met.
- The test torque shall be applied in a minimum of 4 steps up to the nominal torque as defined in the gearbox specification.
- The test shall dwell at each torque step until the sump and bearing temperatures are stable with normal cooling.
- After each torque step, the contact pattern shall be documented. For inaccessible meshes, other methods for the validation of the contact pattern shall be applied e.g. tooth root strain gauges. These contact patterns shall be compared with the assumptions made in the design.
- At planetary stages, the dynamic load share (the product of $K_v \cdot K_\gamma$) at each torque step shall be measured using tooth root strain gauges.
- Measured parameters such as temperatures, pressures and vibration shall be comprehensively logged. The data shall be stored with an unambiguous relationship to each other and, as far as possible, in a format which can be processed electronically.
- On completion of the prototype test at the test bench, the gearbox shall be so disassembled that the condition of all bearings, gears, shafts etc. can be assessed and documented.
- If the test results do not meet the criteria listed in the gearbox specification, then recalculations/redesign shall be performed.

10.7.3 Scope of the prototype test at the wind turbine

The following items at least shall be observed before and during the test of wind turbine gearboxes at the wind turbine:

- The duration of the operation at the wind turbine shall be specified in consultation with GL. The test shall continue at least until the nominal load of the gearbox is reached. If this load cannot be reached, a lower load can be accepted in consultation with GL.
- Relevant operational parameters such as temperatures, pressures and vibration shall be comprehensively logged and evaluated, together with parameters concerning the load on the gearbox. In addition to the torque, these shall include the loads resulting from the integration of the gearbox within the wind turbine.
- After the test, the gearbox shall be visually inspected, including a check of contact patterns and an oil analysis.
- If the test results do not meet the criteria listed in the gearbox specification, then a redesign shall be performed.

10.7.4 Documentation of the prototype tests

All phases of the prototype tests shall be comprehensively documented and evaluated, e.g. by means of measurement data files, photographs, oil analyses, and inspection or assembly reports. As an important part of the evaluation, an appropriate plan shall be defined for the tests of the series gearboxes. The documentation and evaluation shall be submitted, together with the plan for the tests of series gearboxes, to GL for assessment.

10.8 Witnessing of the Commissioning

10.8.1 General

(1) The commissioning procedure shall be witnessed at one of the first wind turbines. The objective of this witnessing is the visual inspection of a plant by the certifier and the assessment of the safety-related tests in the commissioning manual (see Section 9.2).

(2) The wind turbine at which the witnessing of the commissioning is performed shall conform, to the greatest possible extent, to the design on which the Design Assessment is based. The configuration of the turbine to be inspected shall be confirmed in a declaration by the manufacturer to be submitted to GL prior to the witnessing. This declaration shall list at least the types and serial numbers of the main components such as rotor blade, rotor brake, gear box, generator, converter, power transformer, tower, yaw motor and gear, pitch motor and gear and additionally of the electrical cabinets. Any deviation from the design on which the Design Assessment is based shall be reported to GL. Furthermore, the serial number of the wind turbine, the number of the wind turbine in the wind farm, and the location of the wind farm shall be indicated.

(3) The witnessing of the commissioning shall be performed by two experts from GL: one each from the fields of electrical engineering and safety technology.

(4) Successful execution of the witnessing of the commissioning is a prerequisite for issuance of the A-Design Assessment.

10.8.2 Procedure for witnessing

(1) The wind turbine is inspected and the technical execution is compared to the design on which the Design Assessment is based using the declaration from the manufacturer mentioned in Section 10.8.1, para 2.

(2) Compliance with any restrictions and/or conditions expressed in the Certification Reports (reporting the assessment of the design documentation, see Section 1.2.2.4) is assessed as far as possible.

(3) Selected tests from the commissioning manual are carried out with a focus on the safety tests. In addition, the practicability of the tests is verified and the turbine behaviour is assessed for compliance with the design documents.

(4) Possible testing of software functions in the safety system (see Section 2.2.3.3, para 8).

10.8.3 Scope of inspection for electrical engineering

The type of the electrical components and the incorporation of the electrical installations and lightning protection system in the wind turbine shall be inspected. The inspection mainly comprises the following fields:

- installation of the electrical cabinets (earthing, connection of the incoming cables, fill factor of cable channels etc.)
- installation of generator, frequency converters and motors (earthing, check of rating plates etc.)
- cable routing and installation (bending radius, distance between cables according to the specified installation method, installation of cable loop in yaw section, installation and filling factor of cable trays and pipes, connection of shields, identification of cables in accordance with the wiring diagrams etc.)
- installation of the lightning protection system (installation of down conductor system, installation of brushes, spark gaps and surge arresters, measures taken for protection of wind measurement sensors, connection of the down conductor system to the earth electrode, installation of bonding bars, achievement of shielding measures etc.)
- inspection of protection settings and their permanent marking according to Section 8.7.3.3, para 2 and 8.7.3.1, para 2

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11 Periodic Monitoring

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11.1 Scope and Execution

11.1.1 General

11.1.1.1 Objective of Periodic Monitoring

(1) Periodic Monitoring is an inspection of the wind turbine by a technical expert of GL. The inspection shall be carried out according to the conditions in the Certification Reports. Inspection intervals are laid down in the corresponding Certification Reports, their annexes, or indirectly in the form of references.

(2) The objective of Periodic Monitoring is the examination (inspection) of the entire wind turbine including the machinery, the safety devices and the structural integrity.

(3) The body responsible for the wind turbine (called the operator in the following) shall arrange for Periodic Monitoring.

(4) The operator shall file the Inspection Report for the operating life of the wind turbine.

11.1.1.2 Requirements for the technical expert

(1) Periodic Monitoring shall be carried out by a technical expert for wind turbines who is approved by GL. The expert shall have the necessary technical knowledge for assessment of the complete wind turbine. The relevant training and a continuous exchange of experience shall be proven.

(2) The technical expert shall be independent of the operator and wind turbine manufacturer and shall have access to the relevant technical documentation of the wind turbine.

11.1.2 Scope and execution

11.1.2.1 Execution of Periodic Monitoring

During Periodic Monitoring, the complete wind turbine including the rotor blades shall be inspected thoroughly. A specific checklist for the inspection shall be prepared on the basis of the documentation. The checklist shall also contain the assessment criteria.

11.1.2.2 Assessment of the results

The results of the Periodic Monitoring shall be assessed on the basis of the “Guideline for the Certification of Wind Turbines” of GL in its latest edition. Standards and regulations valid at the site shall be observed and applied.

11.1.2.3 Documentation of the wind turbine to be inspected

(1) At least the following documentation shall be perused for Periodic Monitoring:

- approval and/or certification reports including all annexes and supplements
- building permit, including all annexes
- operating manual
- commissioning report
- maintenance reports
- reports of previous Periodic Monitorings or condition surveys (if relevant)
- proof of oil quality
- documentation of modifications/repairs of the turbine and necessary approvals, if relevant

(2) The documentation shall be perused regarding:

- completeness
- compliance with the requirements
- compliance with the maintenance terms, maintenance carried out at regular intervals
- observance of the conditions
- construction according to certified documents
- abnormalities in the life cycle of the wind turbine
- test documents
- adequate execution of the safety tests
- if applicable: execution of modifications / repairs according to approval

11.1.2.4 Scope of Periodic Monitoring

(1) The complete turbine shall be checked by visual inspection, whereby the individual components (including the rotor blades) shall be examined closely and the areas to be examined shall be cleaned or uncovered if relevant.

(2) Structural integrity of the wind turbine including machinery, and functioning of the safety and braking systems, shall be checked as well (see Table 11.1.1).

Table 11.1.1 Scope of inspections for Periodic Monitoring

Assembly	Inspection for / possible defects
Rotor blade	- surface damage, cracks, structural discontinuities (visual and structural examination using suitable methods (e.g. tapping, ultrasonic testing)) - pretensioning of bolts - condition of the lightning protection system as well as indications of any lightning strikes
Drive train	- leakages, unusual noises, vibrations, condition of the corrosion protection, greasing, pretensioning of bolts - condition of the gearing (oil sample, if relevant)
Nacelle and force- and moment-transmitting components	- corrosion, cracks, unusual noises, greasing - pretensioning of bolts
Hydraulic system, pneumatic system	- damage, leakages, corrosion - function
Safety devices, sensors and braking systems	- functional checks, compliance with the limiting values - damage, wear
Electrical installations including control system	- protocols of inspections performed according to the scope described in IEC 60364-6 since the last Periodic Monitoring - availability of up-to-date circuit diagrams - corrosion, protection against direct contact, scorch marks, damages and deterioration of electrical installations incl. electrical cabinets, cable routing and fixing, cable harness in yaw section, connection and housing of sensors and actuators - grounding of electrical components - integrity of hazard beacon and emergency light - settings of protection devices - plausibility function checks of control system incl. verification of limit values and error messages - lock of transformer room - condition and fixing of power transformers - availability of personal safety equipment against electrical shock - labelling (warning signs, danger notices, identification of cables and devices)
Lightning protection system	- protocols of inspections performed according to the scope described in IEC 61400-24 since the last Periodic Monitoring - condition of the air termination and down conduction system as well as indications of any lightning strikes. This mainly includes: condition of receptors, condition of lightning rods, condition of foundation connection lugs, corrosion of earth electrodes, conditions of SPDs, condition of sliding contacts, earth brushes and spark gaps, condition of connections and fixings, condition of down conductors.
Tower and foundation	- corrosion, cracks - pretensioning of bolts - covering of foundation

11.2 Technical Experts, Documentation and Actions

11.2.1 Technical experts

(1) Periodic Monitoring is carried out by the technical experts of GL:

GL Industrial Services GmbH
Renewables Certification
Brooktorkai 18
20457 Hamburg
Germany
Phone: +49 40 36149-707
Fax: +49 40 36149-1720

GL Garrad Hassan
WINDTEST Kaiser-Wilhelm-Koog GmbH
Brooktorkai 18
20457 Hamburg
Germany
Phone: +49 40 36149-702
Fax: +49 40 36149-5920

GL Garrad Hassan
WINDTEST Kaiser-Wilhelm-Koog GmbH
Sommerdeich 14 b
25709 Kaiser-Wilhelm-Koog
Germany
Phone: +49 4856 901-0
Fax: +49 4856 901-49

WIND-consult GmbH
Reuterstrasse 9
18211 Rostock-Bargeshagen
Germany
Phone: +49 38203 507-25
Fax: +49 38203 507- 23

(2) In consultation with the contractor, several experts may perform the monitoring of large wind farms at the same time.

(3) Reports of other technical experts may be accepted.

11.2.2 Documentation

(1) The Inspection Report on the Periodic Monitoring shall be written and signed by the technical expert. The Inspection Report shall contain the following information at least:

- manufacturer, type and serial numbers of the wind turbine and the tower
- location and operator of the wind turbine
- operating hours and total energy produced
- date and weather on the day of inspection
- persons present at the inspection
- detailed description of the scope of inspection
- remarks and damage/deficiencies found
- result of inspection

(2) The result, the deficiencies found and the necessary conditions and restrictions shall be stated on one of the first pages.

(3) Two copies of the report shall be submitted to the operator.

11.2.3 Actions

11.2.3.1 Repairs

(1) In his Report (see Section 11.2.2), the technical expert shall state any deficiencies found and shall prescribe a timeframe for competent repair.

(2) Any repairs necessary shall be carried out on arrangement by the operator.

(3) Repairs shall be carried out by the manufacturer of the wind turbine, by a workshop authorized by the manufacturer, or by a workshop specialized in that field and possessing the necessary knowledge, information and equipment.

11.2.3.2 Decommissioning and recommissioning

(1) If deficiencies endanger the structural integrity of the wind turbine partly or completely, or if deficiencies can be expected to result in greater damage, the technical expert shall recommend the decommissioning of the turbine. Decommissioning shall then be carried out by the operator.

(2) The technical expert shall inform the body responsible for the building permit if public safety is endangered due to the deficiencies and if the operator refuses to decommission the wind turbine.

(3) After repair of the turbine by a specialized workshop according to Section 11.2.3.1, the workshop shall attest the proper repair of the safety shortcomings in writing to the operator. After that, the operator/owner may initiate the recommissioning.

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