

Contents	Page
FOREWORD.....	7
INTRODUCTION.....	9
1 Scope.....	10
2 Normative references	10
3 Terms, definitions and conventions.....	12
3.1 Terms and definitions	12
3.2 Conventions	15
4 Symbols, abbreviations and units	17
4.1 Symbols and units	17
4.2 Abbreviations	21
5 Design for reliability.....	23
5.1 Design lifetime and reliability.....	23
5.2 Design process	24
5.3 Documentation	26
5.4 Quality plan.....	26
6 Drivetrain operating conditions and loads	27
6.1 Drivetrain description	27
6.1.1 General	27
6.1.2 Interface definition.....	27
6.1.3 Specified requirements across interfaces.....	28
6.2 Deriving drivetrain loads.....	28
6.2.1 Wind turbine load simulation model	28
6.2.2 Wind turbine load calculations	29
6.2.3 Reliability of load assumptions	29
6.3 Results from wind turbine load calculations	29
6.3.1 General	29
6.3.2 Time series.....	30
6.3.3 Fatigue load	30
6.3.4 Extreme loads	31
6.4 Operating conditions	31
6.4.1 General	31
6.4.2 Environmental conditions.....	31
6.4.3 Operating strategies	32
6.5 Drivetrain analysis.....	32
7 Gearbox design, rating, and manufacturing requirements	32
7.1 Gearbox cooling	32
7.2 Gears	33
7.2.1 Gear reliability considerations.....	33
7.2.2 Gear rating	33
7.2.3 Load factors	34
7.2.4 Gear materials.....	36
7.2.5 Subsurface initiated fatigue	37
7.2.6 Gear accuracy	37
7.2.7 Gear manufacturing	37
7.3 Bearings.....	38
7.3.1 General	38

7.3.2	Bearing reliability considerations	38
7.3.3	Bearing steel quality requirements	39
7.3.4	General design considerations.....	39
7.3.5	Bearing interface requirements	42
7.3.6	Bearing design issues.....	43
7.3.7	Bearing lubrication.....	46
7.3.8	Rating calculations	47
7.4	Shafts, keys, housing joints, splines and fasteners	50
7.4.1	Shafts.....	50
7.4.2	Shaft-hub connections	50
7.4.3	Flexible splines.....	51
7.4.4	Shaft seals	51
7.4.5	Fasteners	51
7.4.6	Circlips (snap rings).....	52
7.5	Structural elements	52
7.5.1	Introduction	52
7.5.2	Reliability considerations	53
7.5.3	Deflection analysis	53
7.5.4	Strength verification.....	53
7.5.5	Static strength assessment.....	54
7.5.6	Fatigue strength assessment.....	58
7.5.7	Material tests.....	62
7.5.8	Documentation	63
7.6	Lubrication	63
7.6.1	General considerations	63
7.6.2	Type of lubricant.....	64
7.6.3	Lubricant characteristics	65
7.6.4	Method of lubrication	66
7.6.5	Oil quantity	67
7.6.6	Operating temperatures	68
7.6.7	Temperature control	68
7.6.8	Lubricant condition monitoring	69
7.6.9	Lubricant cleanliness	69
7.6.10	Lubricant filter	70
7.6.11	Ports	71
7.6.12	Oil level indicator.....	71
7.6.13	Magnetic plugs	71
7.6.14	Breather	72
7.6.15	Flow sensor	72
7.6.16	Serviceability.....	72
8	Design verification	72
8.1	General	72
8.2	Test planning	72
8.2.1	Identifying test criteria	72
8.2.2	New designs or substantive changes	73
8.2.3	Overall test plan	73
8.2.4	Specific test plans	73
8.3	Workshop prototype testing	74
8.3.1	General	74

8.3.2	Component testing	74
8.3.3	Workshop testing of a prototype gearbox	74
8.3.4	Lubrication system testing	75
8.4	Field test	75
8.4.1	General	75
8.4.2	Validation of loads	75
8.4.3	Type test of gearbox in wind turbine	76
8.5	Production testing	77
8.5.1	Acceptance testing	77
8.5.2	Sound emission testing	77
8.5.3	Vibration testing	77
8.5.4	Lubrication system considerations	77
8.5.5	System temperatures	77
8.6	Robustness test	77
8.7	Field lubricant temperature and cleanliness	77
8.8	Bearing specific validation	78
8.8.1	Design reviews	78
8.8.2	Prototype verification/validation	78
8.9	Test documentation	79
9	Operation, service and maintenance requirements	79
9.1	Service and maintenance requirements	79
9.2	Inspection requirements	79
9.3	Commissioning and run-in	79
9.4	Transport, handling and storage	80
9.5	Repair	80
9.6	Installation and exchange	80
9.7	Condition monitoring	80
9.8	Lubrication	80
9.8.1	Oil type requirements	80
9.8.2	Lubrication system	80
9.8.3	Oil test and analysis	81
9.9	Operations and maintenance documentation	81
Annex A (informative)	Examples of drivetrain interfaces and loads specifications	82
Annex B (informative)	Gearbox design and manufacturing considerations	93
Annex C (informative)	Bearing design considerations	96
Annex D (informative)	Considerations for gearbox structural elements	122
Annex E (informative)	Recommendations for lubricant performance in wind turbine gearboxes	125
Annex F (informative)	Design verification documentation	140
Annex G (informative)	Bearing calculation documentation	143
	Bibliography	151
	Figure 1 – Shaft designation in 3-stage parallel shaft gearboxes	15
	Figure 2 – Shaft designation in 3-stage gearboxes with one planet stage	16
	Figure 3 – Shaft designation in 3-stage gearboxes with two planet stages	17
	Figure 4 – Design process flow chart	25
	Figure 5 – Examples of bearing selection criteria	39

Figure 6 – Blind bearing assembly	45
Figure 7 – Definition of section factor $n_{pl,\sigma}$ of a notched component	56
Figure 8 – Idealized elastic plastic stress-strain curve	57
Figure 9 – Synthetic S/N curve (adapted from Haibach, 2006)	60
Figure A.1 – Modular drivetrain	82
Figure A.2 – Modular drivetrain with 3-point suspension	83
Figure A.3 – Integrated drivetrain.....	83
Figure A.4 – Reference system for modular drivetrain.....	85
Figure A.5 – Rear view of drivetrain	86
Figure A.6 – Reference system for modular drivetrain with 3-point suspension	87
Figure A.7 – Reference system for integrated drivetrain.....	88
Figure A.8 – Example of rainflow counting per DLC	90
Figure A.9 – Example of load revolution distribution (LRD)	91
Figure C.1 – Load bin reduction by lumping neighbouring load bins	97
Figure C.2 – Consumed life index (CLI)	99
Figure C.3 – Time share distribution	99
Figure C.4 – Effects of clearance and preload on pressure distribution in radial roller bearings (from Brandlein et al, 1999)	102
Figure C.5 – Nomenclature for bearing curvature	103
Figure C.6 – Stress distribution over the elliptical contact area	105
Figure C.7 – Examples of locating and non-locating bearing arrangements.....	114
Figure C.8 – Examples of locating bearing arrangements.....	114
Figure C.9 – Examples of accommodation of axial displacements	114
Figure C.10 – Examples of cross-locating bearing arrangements	115
Figure C.11 – Examples of bearing arrangements with paired mounting.....	115
Figure D.1 – Locations of failure for local (A) and global (B) failure.....	123
Figure D.2 – Local and global failure for two different notch radii	123
Figure D.3 – Haigh-diagram for evaluation of mean stress influence (Haibach, 2006)	124
Figure E.1 – Viscosity requirements versus pitch line velocity.....	126
Figure E.2 – Test apparatus for filterability evaluation.....	134
Figure E.3 – Example for circuit design of combined filtration and cooling system.....	138
Table 1 – Symbols used in the document.....	18
Table 2 – Abbreviations	21
Table 3 – Mesh load factor K_γ for planetary stages	35
Table 4 – Required gear accuracy	37
Table 5 – Temperature gradients for calculation of operating clearance	44
Table 6 – Bearing lubricant temperature for calculation of viscosity ratio, κ	46
Table 7 – Guide values for maximum contact stress at Miner's sum dynamic equivalent bearing load.....	49
Table 8 – Minimum safety factors for the different methods.....	50
Table 9 – Partial safety factors for materials	55
Table 10 – Partial safety factors γ_m for synthetic S/N-curves of cast iron materials.....	61
Table 11 – Recommended cleanliness levels.....	70

Table A.1 – Drivetrain elements and local coordinate systems	84
Table A.2 – Drivetrain element interface dimensions	85
Table A.3 – Interface requirements for modular drivetrain	86
Table A.4 – Interface requirements for modular drivetrain with 3-point suspension	87
Table A.5 – Interface requirements for integrated drivetrain	88
Table A.6 – Engineering data and required design load descriptions	89
Table A.7 – Rainflow matrix example	89
Table A.8 – Example of load duration distribution (LDD)	91
Table A.9 – Extreme load matrix example	92
Table B.1 – Recommended gear tooth surface roughness	94
Table C.1 – Guide values for basic rating life L_{h10} for preliminary bearing selection	96
Table C.2 – Static load factors for radial bearings	101
Table C.3 – Bearing types for combined loads with axial loads in double directions	110
Table C.4 – Bearing types for combined loads with axial loads in single direction	111
Table C.5 – Bearing types for pure radial load	112
Table C.6 – Bearing types for axial load	113
Table C.7 – Bearing selection: Legend	116
Table C.8 – Bearing selection: Low speed shaft (LSS) / planet carrier	117
Table C.9 – Bearing selection: Low speed intermediate shaft (LSIS)	118
Table C.10 – Bearing selection: High speed intermediate shaft (HSIS)	119
Table C.11 – Bearing selection: High speed shaft (HSS)	120
Table C.12 – Bearing selection: Planet bearing	121
Table D.1 – Typical material properties	122
Table E.1 – Viscosity grade at operating temperature for oils with $VI = 90$	127
Table E.2 – Viscosity grade at operating temperature for oils with $VI = 120$	128
Table E.3 – Viscosity grade at operating temperature for oils with $VI = 160$	129
Table E.4 – Viscosity grade at operating temperature for oils with $VI = 240$	130
Table E.5 – Standardized test methods for evaluating WT lubricants (fresh oil)	132
Table E.6 – Non-standardized test methods for lubricant performance (fresh oil)	133
Table E.7 – Guidelines for lubricant parameter limits	136
Table F.1 – Design validation and verification documentation	140