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Responsible committee: PEL/88 Wind turbines

Interested committees:

Title: BS EN IEC 61400-6:2020/ A1 Amendment 1 # Wind energy generation systems

Part 6: Tower and foundation design requirements

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

PROJECT NUMBER:

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SUPERSEDES DOCUMENTS:

88/937/RR**IEC TC 88 : WIND ENERGY GENERATION SYSTEMS**

SECRETARIAT:

Denmark

SECRETARY:

Mrs Christine Weibøl Bertelsen

OF INTEREST TO THE FOLLOWING COMMITTEES:

PROPOSED HORIZONTAL STANDARD:

☐

Other TC/SCs are requested to indicate their interest, if any, in this CDV to the secretary.

FUNCTIONS CONCERNED:

☐ EMC☐ ENVIRONMENT☐ QUALITY ASSURANCE☐ SAFETY☒ SUBMITTED FOR CENELEC PARALLEL VOTING☐ NOT SUBMITTED FOR CENELEC PARALLEL VOTING**Attention IEC-CENELEC parallel voting**

The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this Committee Draft for Vote (CDV) is submitted for parallel voting.

The CENELEC members are invited to vote through the CENELEC online voting system.

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TITLE:

Amendment 1 – Wind energy generation systems – Part 6: Tower and foundation design requirements

PROPOSED STABILITY DATE: 2027

NOTE FROM TC/SC OFFICERS:

In 88/926/RQ, Result of 88/914/Q: Proposed amendment to IEC 61400-6:2020, Wind energy generation systems - Part 6: Tower and foundation design requirements, it was concluded that MT 6 will have to further decide on the next step during the preparatory stage of the amendment.

MT 6 has during to the development of the amendment, decided to submit the document directly as CDV.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –

Part 6: Tower and foundation design requirements

AMENDMENT 1

FOREWORD

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Amendment 1 to IEC 61400-6:2020 has been prepared by subcommittee MT 6: Tower and foundation design, of IEC technical committee TC88: Wind energy generation systems.

The text of this Amendment is based on the following documents:

Draft	Report on voting
88/xxxx/FDIS	88/xxxx/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Amendment is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications/.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Sections as given in this document are replacing or amending the respective sections of IEC 61400-6:2020. The main part of this amendment concerns updated knowledge for the design of L-flanges and modifications required due to changes to IEC 61400-1.

The previous method of fatigue assessment using the Schmidt/Neuper trilinear bolt force curve approximation has been removed from the standard. It has been replaced with a physically more accurate method.

The updated methodology for fatigue assessment of L-flanges has been calibrated such that the target failure probability defined in IEC 61400-1 is achieved. Where existing flange designs are checked with the updated method, over-utilization may be found, which in some cases may show an order of magnitude higher than nominally acceptable damage.

This does not impose an immediate risk for the turbines affected, though, due to the following factors:

- a) In most cases such designs have significant conservatism in the fatigue loads assumed e.g. due to the assumption of uni-directional wind combined with type class turbulence conditions.
- b) Experience shows that broken bolts are almost always found and replaced before a turbine collapses.

Existing flange designs need not be re-assessed using the new method, and existing type or project certification remains valid. In cases where broken bolts are found in operating turbines, the affected flange should be checked with the new methodology. Based on the assessment results and the root causes analysis for the failure, further measures should be defined (e.g. shorter inspection intervals).

2 Normative references

Add the following normative references to IEC 61400-6:2020.

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 898-1, Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread

ISO 898-2, Fasteners – Mechanical properties of fasteners made of carbon steel and alloy steel – Part 2: Nuts with specified property classes

ISO 898-3, Mechanical properties of fasteners made of carbon steel and alloy steel - Part 3: Flat washers with specified property classes

ISO 16047, Fasteners - Torque/clamp force testing

ISO 4759-1, Tolerances for fasteners – Part 1: Bolts, screws, studs and nuts – Product grades A, B and C

ISO 4759-3, Tolerances for fasteners - Part 3: Washers for bolts, screws and nuts - Product grades A, C and F

ISO 965 (all parts), ISO general purpose metric screw threads

3 Terms and definitions

Add the following definitions to IEC 61400-6:2020.

3.1

Bolt assembly

Bolt assemblies comprise fastener, nut(s), optionally washer(s), preloading method and lubrication system

EXAMPLE A stud assembly for tension-tightening may comprise a stud and two roundnuts on each side, without additional washers

NOTE In this standard, the term “bolts” is used for the fastener elements. Instead of (head) bolts, also partially or fully threaded studs with nuts on both ends may be used, if they have the same nominal thread geometry and material properties as bolts from accepted standards.

3.2

Design gap height

k_{design}

Design gap height, defined as the 95% fractile value of the log-normal distribution defined by k_{mean} and COV_k (section 6.7.5.2)

3.3

Unloaded gap height limit

$k_{\text{limit,unloaded}}$

Allowable maximum gap height after mating of flanges, without influence of loading by dead weight of tower section(s) above the flange or preload of bolts

3.4

Loaded gap height limit

$k_{\text{limit,loaded}}$

Allowable maximum gap height after mating of flanges, and after application of e.g. dead weight of tower section(s) above the flange and/or partial preload of bolts

NOTE Conditions at time of measuring the loaded gap height shall be defined by the designer

3.5

Flatness deviation of individual flange

u_{tol}

Allowable flatness deviation as defined in section 6.7.3.1 for the individual flange

4 Symbols and abbreviated terms

Symbols

a	flange dimension (nominal distance from inside of flange to bolt circle diameter)
A	nominal area of the bolt shaft with diameter d
a*	auxiliary value to compute bolt bending moment
a'	reduced effective flange dimension according to Tobinaga/Ishihara
A_{cf}	flange cross section area in circumferential direction
A_{S}	nominal stress area of the bolt in thread
b	weld neck thickness (normally equal to the thickness of the connected tower shell) (in section 6.3.2.3 only)

91	b	flange dimension (nominal distance from bolt circle diameter to middle surface of connected tower shell)
92		
93	$b'_{\{B,D,E\}}$	distance in between plastic hinges for failures modes B, D, E
94	c	flank height of the weld preparation (in section 6.3.2.3 only)
95	c	segment width measured at the middle surface of the shell (tower wall)
96	c_{bcd}	segment width measured at the bolt circle diameter
97	C_D	stiffness of the compression spring q (representing the compressed parts)
98	COV	coefficient of variation
99	COV_k	coefficient of variation of gap height
100	COV_p	coefficient of variation of preload force
101	C_S	spring stiffness of the tension spring (representing the bolts)
102	d	nominal diameter of the bolt
103	D	outer diameter of the flange connection
104	$D_{\{1,2\}}$	auxiliary values to determine coefficients for bolt force polynomial
105	d_b	diameter of the bolt hole
106	DFT_{sbw}	dry film thickness (DFT) of coatings applied to the flange surface beneath washers (sbw), i.e in the contact area between washers and flange
107		
108	D_w	outside diameter of the washer
109	E	Young's modulus of steel
110	F_{p,C^*}	preload bolt force used for modified torque method
111	$F_{p,C'}$	preload bolt force used in the design calculations (design preload)
112	$F_{p,inst.,mean}$	mean preload force after installation
113	$F_{p,mean}$	mean preload after settlement
114	F_S	bolt force
115	$F_S(Z)$	bolt force as a function of external force Z applied on flange segment
116	$F_{S,\{0,1,2,3\}}$	bolt forces for determination of polynomial bolt force model
117	$F_{S,max,FLS}$	bolt force calculated for maximum FLS load level
118	$F_{S,min}$	minimum (constant) bolt force for theoretically fully closed connection under compression
119		
120	$F_{S,loss}$	bolt force used to verify preload loss criterion
121	$F_S'(Z)$	slope (derivative) of bolt force curve as a function of external force Z on flange segment
122		
123	$F_{t,R}$	design value of tension resistance of bolt
124	$F_{U,B}$	limit tension resistance for failure mode B
125	$F_{U,D}$	limit tension resistance for failure mode D
126	f_{ub}	ultimate tensile strength of bolt
127	F_V	preload
128	f_{yb}	nominal yield strength of the bolt material
129	$f_{yb,k}$	characteristic value for yield limit of the bolt
130	$f_{Z,tot}$	total amount of settlement in the connection
131	G	shear modulus of steel
132	G_{RNA}	dead weight of the RNA
133	G_{twr}	dead weight of tower above flange connection considered
134	h_n	flange neck height
135	h_{wp}	distance from flange surface to weld preparation
136	h_{wt}	distance from flange surface to weld toe
137	I_{cf}	flange moment of inertia in circumferential direction (bending moment vector pointing in radial direction)
138		
139	I_{tg}	flange moment of inertia for a bending moment vector pointing in tangential direction
140		
141	k	flange gap height
142	$k(l)$	gap height at position l of total gap length L_{gap}

143	k_{design}	design gap height
144	k_{fac}	stiffness factor to calculate meridional shell stiffness
145	k_{fl}	bending stiffness of the flange
146	$k_{\text{gap,tot}}$	total gap stiffness
147	$k_{\text{limit,loaded}}$	gap height after application of a defined load
148	$k_{\text{limit,unloaded}}$	gap height after mating of flanges without any load
149	k_{mean}	mean gap height
150	k_{measured}	measured gap height
151	k_{seg}	segment stiffness
152	$k_{\text{shell,ini}}$	meridional stiffness of the shell / initial shell stiffness
153	K	shell parameter
154	l	distance from transition radius to weld preparation (in section 6.3.2.3 only)
155	l	length of the bolt between the bolt head and the nut
156	L_{30°	circumferential length measured at mid surface of shell over 30° sector
157	$l_k = L_{\text{gap}}$	spanning length of the gap
158	M	external bending moment
159	m	slope parameter of a fatigue resistance curve
160	M_0	bending moment at $Z = \Delta Z_{dw}$
161	$M_{\text{max,FLS}}$	maximum bending moment included in Markov matrix
162	$M_{\text{mean,i}}$	mean value of entry i in the Markov matrix
163	$M_{\text{min,FLS}}$	minimum bending moment included in Markov matrix
164	$M_{\text{pl,3}}$	plastic limit bending moment for flange or shell
165	$M_{\text{pl,BI}}$	plastic limit bending moment for shell
166	$M_{\text{pl,FI}}$	plastic limit bending moment for flange
167	$M_{\text{pl,N,BI}}$	plastic limit bending moment for shell, including interaction with external tension force N
168		
169	$M_{\text{pl,V,FI}}$	plastic limit bending moment for flange, including interaction with shear force V
170		
171	M_{loss}	bending moment used to calculate bolt force for preload loss check
172	$M_{\text{range,i}}$	moment range of entry i in the Markov matrix
173	M_S	bolt moment
174	$M_S(Z)$	bolt moment curve as function of external force Z
175	$M_{S,\text{min}}$	minimum bending moment for theoretically fully closed connection under compression
176		
177	N	number of cycles
178	n	shell parameter
179	n_{bolts}	number of bolts in flange connection
180	$N_{\text{pl,BI}}$	plastic limit normal force for shell
181	p	load factor of the tension springs
182	p_{95}	95% quantile of the log-normal distribution
183	R_{shell}	mean radius of shell (tower wall)
184	s	shell (tower wall) thickness
185	t	flange thickness
186	t_w	thickness of the washer
187	u	auxiliary displacement value for computation of flange segment stiffness
188	u_{tol}	flatness tolerance for individual flange
189	$u_{\text{tol,1m}}$	flatness tolerance per flange over a circumferential length of 1000mm
190	$u_{\text{tol},30^\circ}$	flatness tolerance per flange over 30° sector
191	$u_{\text{tol},360^\circ}$	flatness tolerance per flange around the entire circumference
192	V	shear force in flange
193	$V_{\text{pl,FI}}$	plastic limit shear force
194	w	flange width

195	W_{twr}	section modulus of the tower with outer diameter D and wall thickness s
196	Z	tower shell force (external force on the segment)
197	$Z_{\{0,1,2,3\}}$	force values to construct tower bolt force model
198	Z_{close}	force at which the connection is theoretically fully closed
199	$Z_{\text{max,FLS}}$	max. segment force from the Markov matrix
200	$\tilde{Z}_2$	auxiliary value needed to compute segment stiffness k_{seg}
201	Z_{tot}	total segment force
202	$Z_{\text{tot}}(M)$	total segment force as a function of external bending moment M
203		
204	$\alpha_{\{0,1,2\}}$	auxiliary values to determine polynomial coefficients
205	α_{gap}	circumferential angle of the gap
206	α_k	stiffness correction factor
207	α_s	flange surface inclination
208	β_s	bending resilience of bolt
209	δ_p	resilience of the clamped parts
210	δ_s	resilience of the bolt
211	ΔF_{pl}	expected reduction of preload force due plastic strain development
212	ΔF_Z	expected reduction of preload force due to settlements
213	ΔZ	range of external force applied to flange segment
214	ΔZ_{dw}	segment force resulting from the dead weight
215	ΔZ_{gap}	force for theoretical closure of flange gap
216	$\Delta \sigma$	combined stress range
217	$\Delta \sigma_{\text{axial}}$	stress range from axial forces in the bolt
218	$\Delta \sigma_{\text{bending}}$	stress range from bending moments in the bolt
219	$\Delta \sigma_c$	reference stress range of resistance S-N-curve
220	λ'	lever arm ratio taking the action point correction into account
221	μ_k	mean value of log-normal distribution for gap heights
222	ν	Poisson's ratio
223	$\chi_{\text{ini},M}$	slope of bending moment function
224	$\chi_{\text{ini},\text{mod}}$	modified initial slope of the polynomial approximation
225	$\chi_{\text{ini},\text{true}}$	true slope of the polynomial approximation
226	γ_{M1}	partial safety factor (PSF)
227		

Abbreviated terms

230	2K-PUR	2 Component Polyurethane
231	BTQP	Bolt Tightening Qualification Procedure
232	COV	Coefficient Of Variation
233	DFT	Dry Film Thickness
234	EP	Epoxy
235	FEA	Finite Element Analysis
236	FLS	Fatigue Limit State
237	HV	“Hochfest vorgespannt” (German designation for high-strength bolts intended for preloading)
238		
239	PUR	Polyurethane
240	RNA	Rotor Nacelle Assembly
241	SCF	Stress Concentration Factor
242	TSM	Thermal Spray Metallizing
243	ULS	Ultimate Limit State

6.3.3 Bolts and anchors

Replace entire section 6.3.3 of IEC 61400-6:2020 with the following.

Generally, standardized bolt assemblies should be used as far as practicable.

NOTE A comparison of local design codes and industry design guidelines practice may be found in Annex A and Annex C.

The material property class for bolt assemblies and anchors shall comply with the requirements stated in ISO 898-1, ISO 898-2 and ISO 898-3. Material properties for bolt sets with metric sizes larger than M39 shall be derived with due consideration of size effects and manufacturing methods.

NOTE 1 Large diameters require different materials and manufacturing methods. ISO 898 testing is obtained directly on the fastener or on machined test pieces with max diameter reduction 25 %. For large bolt sizes, the test specimen would still be too large to be conveniently tested, so the specification should be adapted.

NOTE 2 The material properties derived as per above procedures are valid in the temperature range from -50 °C to +150 °C.

For preloaded connections only bolt sets with either property class 8.8 or 10.9 should be selected.

When non-standardized bolt assemblies are specified by the designer, the product characteristics of the bolt assembly shall be obtained through type testing on at least 5 samples for each required characteristic.

The type testing program shall include at least:

- a) Material properties as per ISO 898-1, ISO 898-2 and ISO 898-3 as applicable
- b) Product grade as per ISO 4759-1, ISO 4759-3, ISO 965-2 and ISO 965-5
- c) Suitability for preloading as per ISO 16047

NOTE Non-standardized bolt assemblies may differ due to non-standardized components (fastener, nut, washer(s)), preloading method and lubrication system, among others.

Type testing should be repeated in case of different nominal diameters, manufacturing methods, material property class, coating type, type and source of material, tightening method.

6.5.2 Partial safety factor

Replace complete section 6.5.2 including footnote 8 with

Partial safety factors shall be chosen based on the applied verification method.

When using EN 1993-1-6:2007 or prEN 1993-1-6:2023, $\gamma_{M1}=1.1$ should be used.

When using the modified expressions for meridional buckling (D.1.2.2) according to EN 1993-1-6:2007+A1:2017, $\gamma_{M1}=1.2$ should be used.

6.7 Ring flange connections

Replace entire section 6.7 of IEC 61400-6:2020 with the following.

6.7.1 General

The regulations stated in 6.7 are valid for both L- and T-flange connections, unless otherwise stated.

6.7.2 Design assumptions and requirements

Ring flange connections shall be tightened in a controlled manner in several steps according to the requirements given in this standard.

The fatigue assessment shall be based on the non-linear bolt force function $F_S=f(Z)$ and bolt moment function $M_S=f(Z)$ from which the fatigue ranges of the bolt force F_S and bolt moment M_S can be read off for a given range of the tower shell force Z (see Figure 1 with illustration for the bolt force).

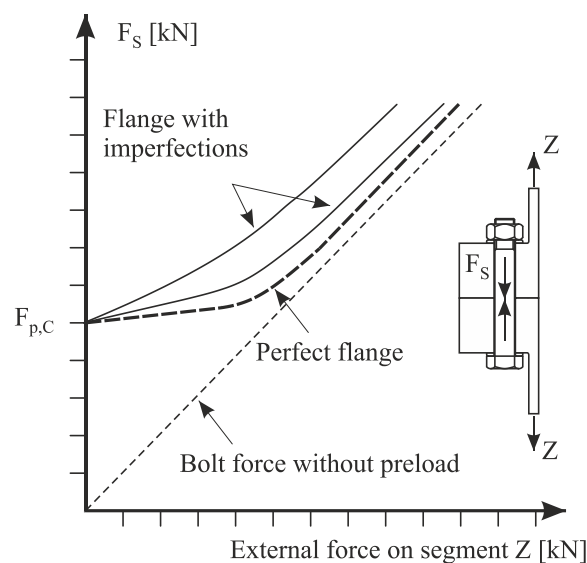


Figure 1 – Bolt force F_S as a function of wall force Z

The stiffness of the flange connection may be assumed as equivalent to the stiffness of the tower shell, and no negative effect from flange opening needs to be considered e.g. for load simulations.

6.7.3 Execution of ring flanges

The tolerances for flange flatness and (if applicable) allowable gaps during installation shall be stated in the drawings or manufacturing specifications and/or installation manuals.

NOTE Flange gaps k in the tower wall region are causing increased fatigue loading of the bolts. Gaps are identified as "parallel gaps" when they occur around part of the circumference with the mating surfaces of the upper and lower flange being parallel to each other. Gaps are identified as "angular gaps" when the mating surfaces are not parallel to each other. Both types can be combined, i.e., a parallel gap can occur on top of an angular gap, see Figure 3. The damage influence of parallel gaps grows with decreasing spanning length l_k over the circumference of the flange for a constant gap height k . Parallel gaps with circumferential lengths of within ~ 30 - 120° of the circumference have the largest damaging effect, as the (design) gap height k increases with gap length l_k . To ensure fatigue strength of the connection, it is necessary to limit the size of the gaps in terms of height and length, such that gaps are sufficiently closed and the pressure body in the flange is created in accordance with requirements for fatigue assessment.