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First edition
2001-04

Wind turbine generator systems –

**Part 23:
Full-scale structural testing of rotor blades**

Aérogénérateurs –

*Partie 23:
Essais en vraie grandeur des structures des pales*

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINE GENERATOR SYSTEMS –

Part 23: Full-scale structural testing of rotor blades

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

IEC 61400-23, which is a technical specification, has been prepared by IEC Technical Committee 88: Wind turbine systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
88/116/CDV	88/137/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

The committee has decided that the contents of this publication will remain unchanged until 2003. At this date, the publication will be

- transformed into an International Standard;
- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

Annexes A, B and C form an integral part of this technical specification.

Annex D is for information only.

Compliance with this technical specification does not relieve any person, organization or corporation of the responsibility of observing other applicable regulations.

INTRODUCTION

The blades of a wind turbine rotor are generally regarded as the most critical components of the wind turbine system. Many national standards address the blades separately in the design, but few require the testing of blades as a requisite for certification. Nevertheless, blade testing laboratories are currently operating in many countries throughout the world. Each laboratory has independently developed a unique set of test equipment, procedures and terminology that are used to test blades. Though each laboratory's techniques may be valid, the results of blade tests done at different facilities may be difficult to compare and evaluate.

The primary emphasis of the IEC TC 88 Working Group 8 effort was to identify commonly accepted practices among the various laboratories and to give guidance in establishing blade test criteria. Due to the wide range of methods (dictated by the test system hardware) used by the various laboratories, writing a restrictive standard that favoured one method to the exclusion of all others would not have been equitable. Therefore, the present technical specification has been written to provide guidelines on recommended practices. Many different methods are included.

The full collection of tests described in this specification should not be considered a requirement for every blade design. The need for tests will depend on the level of uncertainty in the design assessment due to the use of new materials, new design concepts, new production processes, etc. and the possible impact on the structural integrity. In some cases, alternative ways to perform a test are commonly used (see annex D). For the alternatives discussed in this specification, the advantages and disadvantages are noted.

WIND TURBINE GENERATOR SYSTEMS –

Part 23: Full-scale structural testing of rotor blades

1 Scope

This technical specification provides guidelines for the full-scale structural testing of wind turbine blades and for the interpretation or evaluation of results, as a possible part of a design verification of the integrity of the blade.

The following tests are considered in this technical specification:

– static strength tests;
– fatigue tests;
– other tests determining blade properties.

It is assumed that the data required to define the parameters of the test are available. In this technical specification, the design loads and blade material data are considered starting points for establishing and evaluating the test loads. The evaluation of the design loads with respect to the actual loads is outside the scope of this technical specification.

The technical specification is **not** intended to:

– form a detailed specification for the procurement of the test equipment;
– be a detailed work instruction covering all aspects of conducting a strength test;
– be used for establishing basic material strength or fatigue design data for blades and/or components;
– replace a rigorous design process;
– address the testing of mechanism function.

At the time this technical specification was drawn up, full-scale tests were carried out on blades of horizontal axis wind turbines. The blades were mostly made of fibre reinforced plastics and wood/epoxy. However, most principles would be applicable to any WTGS configuration, size and material.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this technical specification. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical specification are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050-415:1999, *International Electrotechnical Vocabulary – Part 415: Wind turbine generator systems*

IEC 61400-1:1999, *Wind turbine generator systems – Part 1: Safety requirements*

ISO 2394:1998, *General principles on reliability for structures*

ISO/IEC 17025:1999, *General requirements for the competence of calibration and testing laboratories*

3 Definitions

For the purpose of this technical specification, definitions related to wind turbines or wind energy in general, given in IEC 60050-415 apply, as well as the following definitions, which are more specific to this publication.

3.1
actuator
device that can be controlled to apply a constant or varying force and displacement

3.2
blade
rotating, aerodynamically active part of the rotor

3.3
blade root
that part of the rotor blade that is connected to the hub of the rotor

3.4
buckling
failure mode characterized by a non-linear increase in deflection with a change in compressive load

3.5
chord
length of a reference straight line (the chord line) that joins, by certain defined conventions, the leading and trailing edges of a blade aerofoil cross-section

3.6
constant amplitude loading
during a fatigue test, the application of load cycles with a constant amplitude and mean value

3.7
creep
time-dependant increase in strain under a sustained load

3.8
design loads
loads the blade is designed to withstand, including appropriate partial safety factors

3.9
edgewise
direction that is parallel to the local chord

3.10
fatigue formulation
methodology by which the fatigue life is estimated

3.11
fatigue strength
measure of the load-bearing capacity of a material or structural element subjected to repetitive loading

3.12
fatigue test
test in which a cyclic load of constant or varying amplitude is applied to the test specimen

3.13
fixture
component or device to introduce loads or to support the test specimen

3.14
flapwise
direction that is perpendicular to the surface swept by the undeformed rotor blade axis

3.15
flatwise
direction that is perpendicular to the local chord, and spanwise blade axis

3.16
full-scale test
test carried out on the actual structure or component

3.17
inboard
towards the blade root

3.18
lead-lag
direction that is parallel to the plane of the swept surface and perpendicular to the longitudinal axis of the undeformed rotor blade

3.19
load envelope
collection of maximum design loads in all directions and spanwise positions

3.20
modal tests
test carried out to determine the natural frequencies, damping and mode shapes of a structure

3.21
natural frequency
(eigen frequency) frequency at which a structure will vibrate when perturbed and allowed to vibrate freely

3.22
non-destructive testing (NDT)
inspection methods that do not alter the properties of the structure

3.23
outboard
towards the blade tip

3.24
partial safety factors
factors that are applied to loads and material strengths to account for uncertainties in the representative (characteristic) values

3.25
point loading
load or series of loads that are applied at discrete spanwise positions

3.26
radial position
the distance from the rotor centre in a plane perpendicular to the rotor axis

3.27
R-ratio
ratio between minimum and maximum value during a load cycle

3.28
service loads
load spectrum, including sequence, which is representative of the actual operating conditions

3.29
S-N formulation
method used to describe the stress (S) vs. cycle (N) characteristics of a material, component or structure

3.30
spanwise
direction parallel to the longitudinal axis of a rotor blade

3.31
static test
test in which a specified load of constant magnitude and direction is applied to a test specimen

3.32
stiffness
ratio of change of force (or torque) to the corresponding change in displacement of an elastic body

3.33
strain
ratio of the elongation (or shear displacement) of a material subject to stress, to the original length of the material

3.34
tare loads
forces and moments created by gravity

3.35
tested area
region of the test object that experiences the intended loading

3.36
test load
forces and moments applied during a test

3.37
thickness
maximum distance, measured perpendicular to the chord, between the upper and lower surfaces of an aerofoil

3.38
twist
spanwise variation in angle of the chord lines of blade cross-sections

3.39
ultimate strength
measure of the maximum (static) load-bearing capacity of a material or structural element

3.40
variable amplitude loading
application of load cycles of non-constant mean, and/or cyclic range

3.41
Whiffle tree
device for distributing a single load source over multiple points on a test specimen

4 Notation

4.1 Symbols

F_x	flapwise shear force (rotor co-ordinate system)
F_y	lead-lag shear force (rotor co-ordinate system)
F_z	spanwise (tensile) force (rotor co-ordinate system)
M_x	lead-lag bending moment (rotor co-ordinate system)
M_y	flapwise bending moment (rotor co-ordinate system)
M_z	blade torsional moment (rotor co-ordinate system)
F_a	flatwise shear force (chordwise co-ordinates)
F_b	edgewise shear force (chordwise co-ordinates)
F_c	spanwise (tensile) force (chordwise co-ordinates)
M_a	edgewise bending moment (chordwise co-ordinates)
M_b	flatwise bending moment (chordwise co-ordinates)
M_c	blade torsional moment (chordwise co-ordinates)
D	theoretical damage
C	conversion factors for material strength
f	strength
F	load
q	strength parameter

4.2 Greek symbols

γ	partial factor
σ	applied stress or strain

4.3 Subscripts

design	design loading conditions
df	design load: fatigue
du	design load: static
ef	uncertainty in fatigue formulation of test load
f	load
ff	fatigue load
fu	static load

k	characteristic value
m	material
n	consequence of failure
nf	consequence of failure in fatigue
nu	consequence of failure in fatigue
sf	blade to blade variation: fatigue test load
su	blade to blade variation: static test load
target	target loading conditions
test	test loading conditions

4.4 Abbreviations

SSF	Static strength factor
RSSF	Relative SSF
MSS	Minimum static strength
RMSS	Relative MSS
FSF	Fatigue stress factor
RFSF	Relative FSF
MFS	Minimum fatigue strength
RMFS	Relative MFS
WGTS	Wind Turbine Generator System(s)

5 General principles

5.1 Purpose of tests

The fundamental purpose of a wind turbine blade test is to demonstrate to a reasonable level of certainty that a blade type, when manufactured according to a certain set of specifications, has the prescribed reliability with reference to specific limit states, or, more precisely, to verify that the specified limit states are not reached and the blades therefore possess the strength and service life provided for in the design. It must be demonstrated that the blade can withstand both the ultimate loads and the fatigue loads to which the blade is expected to be subjected during its designed service life.

Normally, the full-scale tests dealt with in this technical specification are tests on a limited number of samples; only one or two blades of a given design are tested, so no statistical distribution of production blade strength can be obtained. Although the tests do give information valid for the blade type, they cannot replace either a rigorous design process or the quality system for series blade production.

5.2 Limit states

To establish and evaluate the test load, a certain amount of information about the design must be known. Usually the blades are designed according to some standard or code of practice such as IEC 61400-1 that uses the principles of ISO 2394 defining the limit states and partial coefficients, which have to be applied to obtain the corresponding design values. Simply expressed, the limit state is the maximum load that a structure can sustain and still meet the design requirements. The partial coefficients reflect uncertainties and are chosen – at least in principle – in order to keep the probability of a limit state being reached below a certain value prescribed for the structure. According to this, a blade should pass the test if the limit state is not reached when the blade is exposed to the test load, representative of the design load.