



BSI Standards Publication

Wind energy generation systems

Part 50-1: Wind measurement — Application of meteorological mast, nacelle and spinner mounted instruments

National foreword

This British Standard is the UK implementation of EN 61400-50-1:2022. It is identical to IEC 61400-50-1:2022.

The UK participation in its preparation was entrusted to Technical Committee PEL/88, Wind turbines.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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© The British Standards Institution 2023
Published by BSI Standards Limited 2023

ISBN 978 0 539 18338 2

ICS 27.180

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2023.

Amendments/corrigenda issued since publication

Date

Text affected

ICS 27.180

Supersedes EN 61400-12-2:2013 (partially); EN 61400-12-2:2013/AC:2016-10 (partially); EN 61400-12-1:2017 (partially); EN 61400-12-1:2017/AC:2019-12 (partially); EN 61400-12-1:2017/AC:2020-04 (partially); EN 61400-12-1:2017/AC:2021-06 (partially)

English Version

Wind energy generation systems - Part 50-1: Wind
measurement - Application of meteorological mast, nacelle and
spinner mounted instruments
(IEC 61400-50-1:2022)

Systèmes de génération d'énergie éolienne - Partie 50-1:
Mesurages du vent - Application d'instruments
météorologiques montés sur mât, nacelle et nez de rotor
(IEC 61400-50-1:2022)

Windenergieanlagen - Teil 50-1: Windmessungen - Einsatz
von meteorologischen Mast-, Gondel- und Spinner-
Instrumenten
(IEC 61400-50-1:2022)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

The text of document 88/902/FDIS, future edition 1 of IEC 61400-50-1, prepared by IEC/TC 88 "Wind energy generation systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 61400-50-1:2022.

The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2023-09-21
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2025-12-21

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In the official version, for Bibliography, the following notes have to be added for the standard indicated:

IEC 61400-50-2 NOTE Harmonized as EN IEC 61400-50-2

IEC 61400-1:2019 NOTE Harmonized as EN IEC 61400-1:2019 (not modified)

Annex ZA

(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
ISO 2533	1975	Standard Atmosphere	-	-
ISO 3966	-	Measurement of fluid flow in closed conduits - Velocity area method using Pitot static tubes	-	-
ISO/IEC Guide 98-3	2008	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Wind energy generation systems –
Part 50-1: Wind measurement – Application of meteorological mast, nacelle and
spinner mounted instruments**

**Systèmes de génération d'énergie éolienne
Partie 50-1: Mesurages du vent – Application d'instruments météorologiques
montés sur mât, nacelle et nez de rotor**

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ICS 27.180

ISBN 978-2-8322-5937-5

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –**Part 50-1: Wind measurement – Application of meteorological mast,
nacelle and spinner mounted instruments**

FOREWORD

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IEC 61400-50-1 has been prepared by IEC technical committee 88: Wind energy generation systems. It is an International Standard.

This first edition of IEC 61400-50-1 is part of a structural revision that cancels and replaces the performance standards IEC 61400-12-1:2017 and IEC 61400-12-2:2013. The structural revision contains no technical changes with respect to IEC 61400-12-1:2017 and IEC 61400-12-2:2013, but the parts that relate to wind measurements, measurement of site calibration and assessment of obstacle and terrain have been extracted into separate standards.

The purpose of the re-structure was to allow the future management and revision of the power performance standards to be carried out more efficiently in terms of time and cost and to provide a more logical division of the wind measurement requirements into a series of separate standards which could be referred to by other use case standards in the IEC 61400 series and subsequently maintained and developed by appropriate experts.

The text of this International Standard is based on the following documents:

Draft	Report on voting
88/902/FDIS	88/916/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 International Standard 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/standardsdev/publications.

A list of all parts in the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

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.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 61400 specifies procedures and methods which ensure that wind measurements using cup or sonic anemometers mounted on meteorological masts or wind turbine nacelles/spinners are carried out and reported consistently and in accordance with best practice. This document does not define the purpose or use case of the wind measurements. However, as this document forms part of the IEC 61400 series of standards, it is anticipated that the wind measurements carried out in accordance with this standard will be used in relation to some form of wind energy testing or resource assessment.

The main clauses of this document are not mutually dependent. Therefore, it is possible that a user will refer to only certain of the main clauses rather than all clauses to adapt this document to their specific use case. However, the main clauses are presented in a logical sequence that could be applied in practice.

The technical content of this document could previously be found in IEC 61400-12-1:2017 and IEC 61400-12-2:2013.

NOTE A technical correction to the value of the tolerance of the anemometer mounting tube has been made in 10.2.

Due to the increasing complexity of these source documents, IEC TC 88 decided that a re-structuring of the IEC 61400-12 series of standards into a number of more specific parts would allow more efficient management and maintenance going forward. This document has been created as part of that re-structuring process. The requirements on wind measurement specific to the use cases described in IEC 61400-12-1:2017 and IEC 61400-12-2:2013 (for example, the required location of the meteorological mast relative to the test turbine and the height of wind measurement relative to hub height) remain within the new editions of IEC 61400-12-1 and IEC 61400-12-2.

WIND ENERGY GENERATION SYSTEMS –

Part 50-1: Wind measurement – Application of meteorological mast, nacelle and spinner mounted instruments

1 Scope

IEC 61400-50 specifies methods and requirements for the application of instruments to measure wind speed (and related parameters, e.g. wind direction, turbulence intensity). Such measurements are required as an input to some of the evaluation and testing procedures for wind energy and wind turbine technology (e.g. resource evaluation and turbine performance testing) described by other standards in the IEC 61400 series. This document is applicable specifically to the use of wind measurement instruments mounted on meteorological masts, turbine nacelles or turbine spinners which measure the wind at the location at which the instruments are mounted. This document excludes remote sensing devices which measure the wind at some location distant from the location at which the instrument is mounted (e.g. vertical profile or forward facing lidars). This document specifies the following:

- a) the classification parameters for cup and sonic anemometers such that the uncertainty in wind speed measurement for a specific type and model of anemometer exposed to a certain class of environmental conditions can be assessed;
- b) the procedure and requirements for classifying cup and sonic anemometers as, for example, part of the type testing of a specific anemometer model and type;
- c) the procedures and requirements for wind tunnel calibration of anemometers;
- d) an additional or alternative method of checking the consistency of the calibration of an anemometer in the field by carrying out an in-situ comparison with another anemometer;
- e) the requirements for the mounting of anemometers and other instruments on meteorological masts;
- f) the assessment of wind speed measurement uncertainty;
- g) reporting requirements.

2 Normative references

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 2533:1975, *Standard atmosphere*

ISO 3966, *Measurement of fluid flow in closed conduits – Velocity area method using Pitot static tubes*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1

accuracy

closeness of the agreement between the result of a measurement and a true value of the measurand

3.2

data set

collection of data sampled over a continuous period

3.3

distance constant

indication of the response time of an anemometer, defined as the length of air that shall pass the instrument for it to indicate 63 % of the final value for a step input in wind speed

3.4

flow distortion

change in air flow caused by obstacles, topographical variations, or other wind turbines that results in the wind speed at the measurement location being different from the wind speed at the wind turbine location

3.5

hub height

<of a wind turbine> height of the centre of the swept area of the wind turbine rotor above the ground at the tower

Note 1 to entry: For a vertical axis wind turbine the hub height is defined as the height of the centroid of the swept area of the rotor above the ground at the tower.

3.6

measurement period

period during which a statistically significant database has been collected for the use case

Note 1 to entry: A power performance test is an example of a use case.

3.7

measurement sector

sector of wind directions from which data are selected for the use case

Note 1 to entry: A measured power curve is an example of a use case.

3.8

obstacle

obstruction that blocks the wind and creates distortion of the flow

Note 1 to entry: Buildings and trees are examples of obstacles.

3.9

power performance

measure of the capability of a wind turbine to produce electric power and energy

3.10**standard uncertainty**

uncertainty of the result of a measurement expressed as a standard deviation

3.11**wind measurement equipment**

meteorological mast-mounted instruments or remote sensing device

3.12**wind shear**

change of wind speed with height

3.13**wind shear exponent**

α

exponent of the power law defining the variation of wind speed with height

Note 1 to entry: This parameter is used as a measure of the magnitude of wind shear and can be otherwise useful. The power law equation is:

$$v_{zi} = v_h \left(\frac{z_i}{H} \right)^\alpha \quad (1)$$

where

v_h is the hub height wind speed;

H is the hub height (m);

v_{zi} is the wind speed at height z_i ;

α is the wind shear exponent.

4 Symbols, units and abbreviated terms

Symbol	Description	Unit
A	swept area of the wind turbine rotor	m ²
B	barometric pressure	Pa
$B_{10\text{min}}$	measured air pressure averaged over 10 min	Pa
C_h	pitot tube head coefficient	
C_{QA}	generalized aerodynamic torque coefficient	
C_T	thrust coefficient	
c	sensitivity factor of a parameter (the partial differential)	
$c_{B,i}$	sensitivity factor of air pressure in bin i	W/Pa
$c_{d,i}$	sensitivity factor of data acquisition system in bin i	
c_{index}	sensitivity factor of index parameter	
$c_{k,i}$	sensitivity factor of component k in bin i	
$c_{T,i}$	sensitivity factor of air temperature in bin i	W/K
$c_{V,i}$	sensitivity factor of wind speed in bin i	Ws/m
$c_{\rho,i}$	sensitivity factor of air density correction in bin i	Wm ³ /kg

Symbol	Description	Unit
d	meteorological mast diameter	m
e	eccentricity	
$F(V)$	Rayleigh cumulative probability distribution function for wind speed	
$F_{a,\gamma}(a,\gamma, \bar{U})$	tilt and yaw response function for the sonic anemometer	
$f(k_b, k_i, k_p, \bar{v}_p, \dots)$	correction function due to interference between the anemometer including its mounting tube and the wind tunnel flow	
H	hub height of wind turbine	m
h	height of obstacle	m
I	inertia of cup anemometer rotor	kg·m ²
$K_{B,t}$	barometer sensitivity	N/m ² V
$K_{B,s}$	barometer gain	
$K_{B,d}$	barometer sampling conversion	
$K_{T,t}$	temperature transducer sensitivity	K/A
$K_{T,s}$	temperature transducer gain	A/V
$K_{T,d}$	temperature transducer sampling conversion	
$K_{p,t}$	pressure transducer sensitivity	
$K_{p,s}$	pressure transducer gain	
$K_{p,d}$	pressure transducer sampling conversion	
k	class number	
k_b	blockage correction factor	
k_c	wind tunnel calibration factor	
k_f	wind tunnel correction factor to other tunnels (only used in uncertainty estimate)	
k_i	correction factor due to interference between the anemometer (including mounting tube) and test section enclosure, also including flow effects due to mounting tubes extending through the enclosure	
k_n	class number of anemometer sample number n ($n = 1, \dots, 5$ or more)	
k_p	correction factor due to interference caused by the anemometer (including mounting tube) on the velocity measured by the pitot tube	
k_ρ	humidity correction to density	
L_m	distance between adjacent legs of lattice meteorological mast	m
L	distance between the wind turbine and the wind measurement equipment	m
M	number of uncertainty components in each bin	
M_A	number of category A uncertainty components	
M_B	number of category B uncertainty components	
m	slope of the regression relating V_{control} to $V_{\text{primary_est}}$	

Symbol	Description	Unit
m	slope of the regression between V_1 and V_2	
N	number of bins	
N_h	number of hours in one year $\approx 8\,760$	h
N_i	number of 10 min data sets in wind speed bin i	
N_j	number of 10 min data sets in wind direction bin j	
n	number of samples within sampling interval	
n_h	number of available measurement heights	
P_w	vapour pressure	Pa
p	axial run-out deviation	
Q_A	aerodynamic torque	N·m
Q_F	friction torque	N·m
R	rotor radius	m
r_a	effective radius of angle measurement	
R_0	gas constant of dry air (287,05)	J/kg·K
R_d	distance to meteorological mast centre	m
R_w	gas constant of water vapour (461,5)	J/kg·K
REWS	rotor equivalent wind speed	
RSD	remote sensing device	
r	correlation coefficient	
s	category A standard uncertainty component	
s_A	category A standard uncertainty of tunnel wind speed time series	
$s_{k,i}$	category A standard uncertainty of component k in bin i	
s_i	combined category A uncertainties in bin i	
S	meteorological mast solidity	
T	absolute temperature	K
TI	turbulence intensity	
$T_{10\min}$	measured absolute air temperature averaged over 10 min	K
t	time	s
U	wind speed	m/s
U_d	centreline wind speed deficit	m/s
U_{eq}	equivalent horizontal wind speed	m/s
U_i	wind speed in bin i	m/s
U_j	wind speed in bin j	
U_{sonic}	sonic anemometer	
U_t	threshold wind speed	m/s
$\vec{U}$	instantaneous wind vector	
u	category B standard uncertainty component	

Symbol	Description	Unit
$u_{B,i}$	category B standard uncertainty of air pressure in bin i	Pa
$u_{c,i}$	combined standard uncertainty of the power in bin i	W
$u_{dVS,i}$	uncertainty component of data acquisition of the wind speed signal	
u_i	combined category B uncertainties in bin i	
u_{index}	category B standard uncertainty of index parameter	
$u_{k,i}$	category B standard uncertainty of component k in bin i	
$u_{M,cc,i}$	influence of measurement in cold climate on the classification of the anemometers	
$u_{V,i}$	category B standard uncertainty of wind speed in bin i	m/s
$u_{VHW,i}$	uncertainty on the hardware used and is one of $u_{VS,i}$, $u_{VR,i}$ or $u_{REWS,i}$	
$u_{VM,i}$	uncertainty related to the method applied	
$u_{VS,class,i}$	uncertainty related to the classification of the sensors	
$u_{VS,igt,i}$	uncertainty related to the flow distortion from lightning finial	
$u_{VS,mnt,i}$	uncertainty related to the mounting of the sensors	
$u_{VS,precal,i}$	uncertainty relating to the pre-calibration	
$u_{VS,postcal,i}$	uncertainty related to the post-calibration	
$u_{v2,i}$	wind speed uncertainty assessment	
$u(t)$	measured wind speed by the cup anemometer at time t using the ordinary calibration function	
u_t	tunnel wind speed	
Δu	difference between wind tunnel wind speed and the indicated wind speed of the cup anemometer, at the beginning of the step response measurement, at time t_0	
V	wind speed	m/s
V_{ave}	annual average wind speed at hub height	m/s
V_{control}	wind speed of the control anemometer	
$V_{\text{control},i}$	wind speed of the control anemometer in bin i	
V_i	normalized and averaged wind speed in bin i	m/s
V_n	normalized wind speed	m/s
$V_{n,i,j}$	normalized wind speed of data set j in bin i	m/s
$V_{\text{primary},i}$	wind speed of the primary anemometer in bin i	
$V_{\text{primary_est}}$	estimated primary anemometer wind speed	
$V_{10\text{min}}$	measured wind speed averaged over 10 min	m/s
V_1	wind speed from sensor one	
V_2	wind speed from the second sensor	
v	transversal wind speed component	m/s

Symbol	Description	Unit
$\bar{v}$	average wind speed at the anemometer position	m/s
$\bar{v}_p$	average wind speed at the reference position	
v_{eq}	measured equivalent wind speed	m/s
WD	wind direction	
WME	wind measurement equipment	
w	vertical wind speed component	m/s
w_i	weighting function to define deviation envelope	
α	wind shear exponent from power law	°
α	pitot static tube head coefficient	
α	angle to be measured (calibration value)	
α_{CL}	wind tunnel centreline	
$\alpha_{Digital}$	uncertainty by digital output signal	
α_{dir}	uncertainties in the determination of flow direction	
$\alpha_{incl.1}$	influence of the angle between the axes of rotation	
α_{item}	uncertainty by mounting the wind direction sensor	
$\alpha_{incl.2}$	uncertainty by possible malposition of the wind direction sensor	
α_{sensor}	uncertainties in the calibration of the reference yawing sensor	
α_{set}	aligning the centreline with the north marking of the wind direction sensor	
α_{Ω}	uncertainty by the determination of the ohmic resistance of a wind direction sensor	
ε_i	deviation in m/s for influence parameter combination i	
$\varepsilon_{max,i}$	maximum deviation for any wind speed bin i in the wind speed range	m/s
θ	disturbed sector	°
κ	von Karman constant 0,4	
λ	speed ratio	
λ_0	speed ratio for $C_{QA} = 0$	
ρ	air density	kg/m ³
τ	the time constant to be determined for the step response (τ_{low} for step response from below and τ_{high} for step response from above)	
ρ_0	reference air density	kg/m ³
ρ_{10min}	derived air density averaged over 10 min	kg/m ³
$\sigma_{P,i}$	standard deviation of the normalized power data in bin i	W
σ_{10min}	standard deviation of parameter averaged over 10 min	
$\sigma_u/\sigma_v/\sigma_w$	standard deviations of longitudinal/transversal/vertical wind speeds	
Φ	relative humidity (range 0 % to 100 %)	

Symbol	Description	Unit
ω	angular speed	s^{-1}
Δp_{ref}	mean differential pressure	

5 General

This document defines methods and requirements for carrying out wind measurements using instruments such as anemometers (cup and ultrasonic) mounted on meteorological masts, wind turbine nacelles (Annex C) and wind turbine spinners (Annex D). Requirements for calibration, classification and mounting are described. Wind measurements carried out in accordance with this document are useable for many purposes in the field of wind energy (e.g. power performance measurement, site assessment, load measurement, noise measurement) as described in other standards in the IEC 61400 series. The specific standard relating to the intended use case of the wind measurements should be referred to for limitations and additional requirements (e.g. height of measurement relative to turbine hub height in the case of power performance measurements). For wind measurements carried out using ground-mounted remote sensing devices (e.g. lidar and sodar), refer to IEC 61400-50-2 [1]¹. Although the wind measurements defined in this document relate mainly to the measurement of wind speed, an example of a procedure defining the calibration of wind direction sensors is provided in Annex A.

6 Classification of cup and sonic anemometry

6.1 General

Cup and sonic anemometers are wind measurement instruments that can be used in a wide range of wind energy related measurements. In order to transfer traceability they shall be calibrated in a wind tunnel in accordance with Clause 8. Wind tunnel calibrations are performed under controlled environmental conditions with a smooth and low turbulent flow. However, during measurements and operation in the field, these instruments are subject to turbulent flow and environmental conditions that can deviate significantly from wind tunnel calibration conditions. The field conditions can significantly influence the instrument characteristics and cause the instrument output to deviate from wind tunnel calibrations. If the ranges of the influence parameters during field operation are determined, then the systematic deviations can be analysed and the deviations in instrument output can be put into a classification scheme.

Known influence parameters on cup anemometer measurements are turbulence, air temperature, air density, and average upflow angle. Known influence parameters on sonic anemometer measurements are wind direction, upflow angle, and air temperature. These influence parameters shall be considered in the classification. Other environmental parameters can influence the instruments. If such influence parameters are known to give systematic deviations, the influence shall be analysed and included in the classification scheme. Furthermore, the combined effect of all influence parameters shall be assessed. The systematic deviations due to influence parameters shall be analysed in accordance with the procedures described in Clause 7 resulting in a classification specification of the type of anemometer. At least five samples of the anemometer type shall be assessed. Modification of an anemometer type that can influence the output requires a new assessment. Change in geometry of the anemometer type, measurement principle, software algorithm for calculation of the output, software settings, or supporting structure geometry, requires a new assessment.

The classification method only considers normal operation of the sensors. The method does not consider, for example, wear, malfunctioning or icing.

¹ Numbers in square brackets refer to the Bibliography.

6.2 Classification classes

The classification of an anemometer type is divided into five classes dependent on the purpose. Classes A, B, C and D are based on predefined terrain and climate ranges, see Table 1. Classes A and C shall be used for terrain that meets the requirements in IEC 61400-12-5 and in type A terrain in IEC 61400-12-3. Classes B and D shall be used for terrain that does not meet the requirements in IEC 61400-12-5. Classes B and D could be used in terrain type B in IEC 61400-12-3. If information about the influence parameter ranges during the measurements are available then class S may be used.

Class S is a special class, where the influence parameter ranges may be defined by the user, see Table 1. This can be for a special climate, for example cold climate conditions. Class S can also be used for uncertainty estimate for a measurement campaign where the influence parameter ranges are determined during the measurements. Class S may be used for measurements in type A, B and C terrain, see IEC 61400-12-3. The classification number k shall be used in determination of the wind speed operational characteristics uncertainty, as listed in 11.3.4. IEC 61400-12-5 provides an assessment of the terrain to evaluate if the flow distortion due to the terrain will be significant. For classification of cup and sonic anemometers, this terrain assessment supports the definition of the classification classes A, B, C and D.

Class A: Associated with terrain that meets the requirements of IEC 61400-12-5 and with general influence parameter ranges for this type of terrain.

Class B: Associated with terrain that does not meet the requirements of IEC 61400-12-5 and with general influence parameter ranges for this type of terrain.

Class C: Same as class A but with temperatures down to -20 °C .

Class D: Same as class B but with temperatures down to -20 °C .

For terrain or climate that deviates from classes A to D, a class S climate may be specified.

Class S: Associated with conditions that deviate from class A, B, C or D. In this class, the user defines the influence parameter ranges. This may be due to special or user defined terrain or climate conditions.

6.3 Influence parameter ranges

The minimum required influence parameter ranges of cup and sonic anemometer classification are listed in Table 1.

6.4 Classification of cup and sonic anemometers

The classification of an anemometer is specified by the amount of systematic deviations from calibrated values (calibration in accordance with Clause 8) where the systematic deviations are determined for values varying within the influence parameter ranges. For a sonic anemometer and for directional sensitive cup anemometers, a reference direction that is used for calibrations in accordance with Clause 8 shall be defined for the instrument type. The systematic deviations shall be derived for all values that are relevant for the class determination between minimum and maximum values for each parameter. The class number k_n of an anemometer sample number n shall be determined as the maximum systematic deviation from the wind tunnel calibration value, weighted with a wind speed function ε_i :

$$k_n = 100 \cdot \max |\varepsilon_i / w_i| \quad (2)$$

where

k_n is the class number of anemometer sample number n ($n = 1, \dots, 5$ or more);

w_i is a weighting function in m/s that defines the deviation envelope, see Equation (3);

ε_i is the deviation in m/s for influence parameter combination i .

NOTE A class number of 1 corresponds to 1 % at 10 m/s but more than 1 % below 10 m/s and less than 1 % above 10 m/s.

The weighting function w_i averages the influence of absolute and relative deviations:

$$w_i = 5 \text{ m/s} + 0,5 \cdot U_i \quad (3)$$

where

U_i is the wind speed in m/s for influence parameter combination i .

Table 1 – Influence parameter ranges (10 min averages) of classes A, B, C, D and S

Parameter	Class A Terrain meets requirements in IEC 61400-12-5 Range	Class B Terrain does not meet requirements in IEC 61400-12-5 Range	Class C Terrain meets requirements in IEC 61400-12-5 Range	Class D Terrain does not meet requirements in IEC 61400-12-5 Range	Class S ^a Special class with user defined ranges Range
Wind speed, V (m/s)	4 to 16	4 to 16	4 to 16	4 to 16	4 to 16
Turbulence intensity	0,03 to (0,12 + 0,48/ V)	0,03 to (0,12 + 0,96/ V)	0,03 to (0,12 + 0,48/ V)	0,03 to (0,12 + 0,96/ V)	User defined
Turbulence ^b structure $\sigma_u/\sigma_v/\sigma_w$	1/0,8/0,5 ^c	1/0,8/0,5 ^c	1/0,8/0,5 ^c	1/0,8/0,5 ^c	User defined or 1/0,8/0,5 ^c
Air temperature (°C)	0 to 40	–10 to 40	–20 to 40	–20 to 40	User defined
Air density (kg/m ³)	0,9 to 1,35	0,9 to 1,35	0,9 to 1,35	0,9 to 1,35	User defined
Average upflow angle (°)	–3 to 3	–15 to 15	–3 to 3	–15 to 15	User defined
Wind direction ^d (°)	Cups and sonics: 0 to 360°	Cups and sonics: 0 to 360°	Cups and sonics: 0 to 360°	Cups and sonics: 0 to 360°	Cups: 0 to 360° Sonics: user defined

^a The influence parameter ranges determined during a specific measurement campaign include some parameters that are measured as part of the measurement: wind speed, turbulence, air temperature, air density. The upflow angle can be determined by mounting a bi-vane or three-dimensional sonic anemometer on the meteorology mast.

^b For generation of artificial wind, see for example 7.4.

^c A non-isotropic Kaimal turbulence spectrum with turbulence length scale 350 m.

^d If a cup anemometer is directionally sensitive (should be investigated on at least one sample), then directivity shall be included in the classification. For sonic anemometers directivity shall always be included in the classification, but for class S the wind direction range may be defined by the user.

For the five anemometer samples being tested for classification, the class is determined by the average of the k values plus half the range divided by $\sqrt{3}$ assuming a rectangular distribution (see Equation (4)).

$$k = \frac{1}{5} \sum_{n=1}^5 k_n + \frac{k_{\max} - k_{\min}}{2} \cdot \frac{1}{\sqrt{3}} \quad (4)$$

A classification, referring to a certain class, is expressed by kA , kB or kS , for example 1,7A or 2,5S. The operational characteristics standard uncertainty (see 11.3.4) of a cup or sonic anemometer can be derived from the classification assuming a rectangular uncertainty distribution, in which case the standard uncertainty to be used in the wind speed uncertainty assessment is:

$$u_{v2,j} = (0,05 \text{ m/s} + 0,005 \cdot U_j) \cdot k / \sqrt{3} \quad (5)$$

An example of a classification is described in Clause 7.

6.5 Reporting format

Reporting of the classification of the wind speed sensor shall specify all relevant details of the sensor, including all settings. Documentation of the class of a sonic anemometer shall specify the programmed configuration for which the classification is valid.

Relevant documentation shall be provided with detailed information on the procedures followed, the measurements performed as background for the classification, and documentation of the facilities and instruments used.

7 Assessment of cup and sonic anemometry

7.1 General

Assessment of anemometry for classification shall be derived from traceable wind tunnel tests, other laboratory tests and associated modelling of anemometer characteristics. A thorough assessment method should also include verification field tests.

An assessment of a type of cup or sonic anemometer shall include verified procedures to determine the influence of the following basic characteristics (also note Table 1):

- a) tilt angular response characteristics;
- b) yaw angular response characteristics;
- c) temperature induced effects on the anemometer performance.

Additionally, for cup anemometers the following characteristics shall be assessed:

- d) dynamic effects due to rotor torque characteristics.

Subclause 7.2 describes procedures for measuring anemometer characteristics. Subclause 7.3 describes a method for classification of cup anemometers with an example and 7.4 describes a method for classification of sonic anemometers. An actual assessment shall be based on the methodologies in 7.3 and 7.4, but could also be based on other assessment methods, as long as they include verified procedures to incorporate the influence of the parameters in Table 1. Subclause 7.5 presents a method for field comparison of anemometers.

7.2 Measurements of anemometer characteristics

7.2.1 Measurements in a wind tunnel for tilt angular response characteristics of cup anemometers

The tilt angular response is the measured wind speed at inclined flow angles relative to the measured wind speed at non-inclined flow. The tilt angular response of a cup anemometer shall be measured in a wind tunnel that fulfils the requirements described in Clause 8. Additionally, it shall be documented that the wind tunnel is sufficient in height for obtaining accurate tilt response characteristics.

The behaviour of an anemometer is strongly influenced by the free space around and especially underneath and above the anemometer. It is important that the tilting mechanism is designed in such a way that the centre of the sensing part of the anemometer is fixed but free to rotate, and the bottom plate of the wind tunnel shall be closed in order to prevent adverse flow effects. Therefore, no translatory motion can be performed by the rotor, instead only an inclination of the rotor plane is realized.

The tilt angle response may be measured with two alternative methods, one using a sweep and the other using fixed positions.

The determination of the anemometer's response to quasi-statically inclined flow should be performed with the help of an automatic tilt angle device installed in the wind tunnel. During the measurements, the anemometer is slowly tilted back and forth with a very slow sweep rate (less than $0,05^\circ/\text{s}$) so the influence on the results due to the angular speed can be neglected. Sweeps may only be used if the wind speed in the wind tunnel is kept within 0,5 % of the nominal wind speed for all tilt angles.

At non-inclined flow the tilt angle shall be fixed and measurements shall be performed for 300 seconds to ensure that sufficient data is collected for the zero bin ($\pm 0,5^\circ$). This zero bin data is used for normalization of the tilt angular response.

Recording of tilt angle, wind tunnel wind speed and anemometer output shall be made simultaneously and averaged. It can be meaningful to incorporate a finer resolution of the bin-averaging algorithm to account for higher gradients in the tilt angle response around zero degrees.

The tilt angular response should alternatively be determined by stepwise fixed position measurements, where the response at each angle is determined by Clause 8 wind tunnel calibration at selected nominal wind speeds in the wind speed range.

Measurement matrix recommendations:

- a) definition of flow angle: positive for upwards flow on cup rotor;
- b) tilt angle range and steps: at least -30° to $+30^\circ$ (for example $\pm 0^\circ$, $\pm 1^\circ$, $\pm 2^\circ$, $\pm 3^\circ$, $\pm 4^\circ$, $\pm 6^\circ$, $\pm 8^\circ$, ..., $\pm 30^\circ$);
- c) wind speed range and steps: 4 m/s to 16 m/s (for example 4 m/s, 8 m/s, 12 m/s and 16 m/s);
- d) bin averaging range for the sweep method: bin width max. 2° .

An example of tilt angular response (including the "ideal" cosine shape) is shown in Figure 1.