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|                  |                        |
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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 | Comment (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.                                       |                                                    |

# DRAFT INTERNATIONAL STANDARD

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## Mechanical vibration — Measurement and evaluation of machine vibration —

### Part 21: Horizontal axis wind turbines

ICS: 17.160; 27.180

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

This first edition of ISO 20816-21 cancels and replaces the older edition of ISO 10816-21:2015, which has been technically revised, considering of VDI 3834-2 for direct drive wind turbines.

The main changes are as follows:

- scope expansion to include Group 2 wind turbine without gearboxes;
- revision of text and content so that the document can be applied to both groups of wind turbines;
- And vibrations of different types of wind turbines are clearly identified and graphics showed measurement positions;
- revision and standardization of assessment tables for both types of wind turbines (see [Annex A](#));
- clarification of descriptions of technical functionality of wind turbines (see [Annex B](#));
- added a proposal for protocols for acceptance measurements (see [Annex D](#));
- updated and supplemented information on relevant documents (see Bibliography).

The list of all parts in the ISO 20816 and ISO 10816 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

The ISO 20816 series of documents provides general guidance relating to the measurement and evaluation of vibration measured on machine rotating and non-rotating parts. This document provides recommendations for the measurement and evaluation criteria for wind turbines. Additional guidance is given to account for the vibration of the wind turbine tower and nacelle caused by the effects of wind, flow disturbances due to the tower (tower dam effect) and the natural vibration of the rotor blades and structure itself (tower and foundation). For offshore wind turbines, guidance is given to take account of the vibration response due to sea swell, which differs from the response of land-based wind turbines in terms of the temporal vibration behaviour and spectra.

ISO 20816-1 deals with the measurement and evaluation of machine vibration and serves as the basis of other documents dealing with specific considerations for different machine types, including wind turbines.

In contrast to the other parts of the ISO 20816 series this document considers vibration not generated by the machine itself, but excited by wind and, in case of offshore wind turbines, additionally by sea swell. Due to the flexibility of the blades and tower and the low rotor rotational speeds, it is necessary to include the low-frequency vibration in the measurement and evaluation criteria.

The construction methods used and the conditions under which wind turbines are built and operated entail, that presenting general guidelines for the vibration evaluation of their structures is not possible. However, the measurement procedures and criteria for evaluating the vibration of their structures explained in ISO 4866 can be used for guidance. Furthermore, offshore wind turbine structural vibration monitoring is covered in VDI 4551.

The necessity to measure and evaluate the low-frequency vibration of the wind turbine components as a response to periodic and stochastic excitation sources requires additional evaluation quantities in contrast to those described in this document. This is complicated by the effects of wind and waves on the wind turbine structure, which can lead to high-amplitude low-frequency vibration.

Due to the influence of the vibration magnitude on the induced stresses of all wind turbine components and thus on their operational reliability and service life, it is in the interest of all stakeholders involved in the manufacture, ownership, operation, service, maintenance, and financing of wind turbines in having a widely accepted document, which provides clear criteria and recommendations regarding the measurement and evaluation of their mechanical vibration.

The aim of this document is to standardize the vibration measurements to be performed, to facilitate their evaluation and to allow a comparative assessment of the measured vibration between different wind turbines and their components. This document does not address the diagnostic evaluation of the condition of the wind turbine components themselves. The evaluation criteria described in this document serve to ensure reliable, safe long-term wind turbine operation.

In addition, evaluation zone boundaries are set, which enable conclusions to be drawn regarding the general state of wind turbine components or the overall system. Evaluation zone boundary values are not intended to be used as contractual acceptance values. Those need to be agreed between the wind turbine manufacturer and wind turbine user.

# Mechanical vibration — Measurement and evaluation of machine vibration —

## Part 21: Horizontal axis wind turbines

### 1 Scope

This document provides information regarding the measurement and evaluation of the mechanical vibration of wind turbines and their components. The working principles of wind turbines covered by this document are described in [Annex B](#).

The installation site and type of wind turbine mechanical drive train used, influence the vibration magnitude, so for the purposes of this document wind turbines have been divided into two groups:

- a) Group 1: Horizontal axis wind turbine installations with generators coupled to the rotor via a gearbox; and
- b) Group 2: Horizontal axis wind turbine installations with generators coupled to the rotor without a gearbox (direct drive wind turbines).

This document applies to both Group 1 and 2 wind turbines with a rated generator output exceeding 200 kW.

This document recommends zones for evaluating the vibration at continuous load operation. However, in most cases these evaluation zone boundaries are not suitable for the early detection of faults. [Annex A](#) presents evaluation zone boundaries based on vibration data collected from thousands of wind turbines with rated generator outputs up to 5 MW which can be helpful in facilitating discussion between users and manufacturers when considering early fault detection.

The evaluation criteria described in this document serve to ensure safe, reliable, long-term operation of the wind turbine and its components. It is intended to standardize the vibration measurements taken, to assist in their evaluation and to facilitate a comparative evaluation of the vibration measured in wind turbines and their components. In addition, recommendations are given for the determination of operational vibration limit values.

The type and implementation of broad-band vibration monitoring methods to be used for wind turbines are addressed in this document, along with evaluation criteria for vibration severity. This document does not address diagnosis or fault detection, although the measurement equipment described can be used for vibration monitoring.

NOTE 1 For information regarding vibration condition monitoring see the ISO 13373 series. For Information regarding condition monitoring and diagnostics of wind turbines see the ISO 16079 series.

NOTE 2 IEC 61400-13 describes load measurements that can be taken using strain gauges mounted on the wind turbine supporting structure and blades. For procedures to assist the detection of rolling bearing and gearbox defects see ISO 13373-2. For the measurement and evaluation of structure-borne noise in wind turbines fitted with rolling bearings see VDI 3832.

NOTE 3 For the strong unbalance influence on vibrations see VDI 3834-1:2015-08, Annex B. In addition to mass unbalance the rotor can also exhibit an intolerable aerodynamic unbalance. The evaluation of balance quality of the slowly turning wind turbine rotor requires special measurement and analysis.

The requirements described in this document do not apply to the acceptance measurements for wind turbine gearboxes and generators taken in the manufacturer's test facility.

NOTE 4 Acceptance measurements for wind turbine gearboxes and generators, taken in the manufacturers test facility, are assessed on ISO 20816-9 and/or IEC 60034-14.

This document does not provide evaluation zones for vibration measurements taken on rotating parts (shaft relative displacement) due to the small number of turbines on which such measurements are/ have been taken.

## 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 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

ISO 2954, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity*

ISO 20816-1, *Mechanical vibration — Measurement and evaluation of machine vibration — Part 1: General guidelines*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041 and the following apply.

### 3.1 assessment acceleration

$a_{w0}$   
broad-band root-mean-square (r.m.s.) value of acceleration in a given frequency band, measured over a fixed period

### 3.2 assessment velocity

$v_{w0}$   
broad-band root-mean-square (r.m.s.) value of vibration velocity in a given frequency band, measured over a fixed period

## 4 Measurement procedures

### 4.1 General

The measurement procedures to be followed and the instrumentation which shall be used are specified in ISO 20816-1, subject to the requirements given in this clause.

Care shall be taken to ensure that the measuring system is not influenced by environmental factors such as:

- a) temperature variation;
- b) magnetic fields, including magnetisation of the wind turbine shaft(s);
- c) external sound fields;
- d) power source variation;
- e) transducer cable runs and faults; and

f) transducer orientation.

Particular attention shall be paid to ensure that the vibration transducers are correctly mounted and that such mountings do not degrade the accuracy of the measurements taken.

## 4.2 Measurement positions

In wind turbines it is common to measure vibration only on non-rotating parts. Where vibration measurements cannot be obtained from sensors mounted on the drive train, selecting sensor positions that represent the vibration of the entire structure can be necessary.

Measurements shall be taken on the bearings, bearing support housing and structural parts of the wind turbine which significantly respond to the dynamic forces applied and characterize the overall vibration of the machine, nacelle and tower. In some wind turbines it is not possible to access the bearing housings directly. In these cases, the measurements taken shall reasonably represent the vibration of the bearing housing and do not include any local resonances or amplification. It can be necessary to confirm the repeatability and validity of the measurements taken from the chosen sensor positions (e.g. by taking measurements in several different positions and comparing the results). If the manufacturer has identified suitable positions to mount vibration transducers on their wind turbine, these should be used.

The chosen sensor positions and directions of vibration measurement taken on the drive train shall provide adequate sensitivity to the machine responses and any external dynamic forces present. Typically, this requires two orthogonal radial measurement positions on each bearing cap or machine housing to be identified and the transducers may be placed at any angular position on the bearing housing or pedestal. The local vertical and horizontal directions are usually preferred for horizontally mounted machines. For components with rolling bearings, the position that gives the maximum vibration reading shall be used.

In some cases, in particular when considering wind turbine structural vibration and any aerodynamic effects, it is recommended to additionally measure in the axial direction of the rotor. The specific measurement positions and directions used shall be recorded for each measurement.

A single transducer may be used, mounted on a bearing cap or pedestal, instead of a pair of orthogonal transducers, if it provides adequate information regarding the severity of the machine vibration. For gearboxes, it is often a single transducer can be used to detect vibration characteristics from multiple bearings or shafts. However, caution shall be exercised when evaluating the vibration values taken from a single transducer since they do not always provide a reasonable approximation to the maximum vibration value for that component (see [Clause 5](#)).

For the appropriate measurement positions for measuring bearing housing vibration see [Figure C.1](#) and [Figure C.2](#) for wind turbines with gearboxes and [Figure D.1](#) to [Figure D.4](#) for direct drive wind turbines.

## 4.3 Measurement equipment requirements

The equipment used shall be capable of measuring broad band r.m.s. vibration with a flat response over a selectable set of frequency ranges. These frequency ranges shall include:

- a) 0,1 Hz to 10 Hz;
- b) 10 Hz to 1 000 Hz;
- c) 10 Hz to 2 000 Hz; and
- d) 10 Hz to 5 000 Hz.

For measurements taken in all frequency ranges, the measuring instruments used, shall meet the requirements of ISO 2954. However, calibration of units at the low frequency of 0,1 Hz are rarely in use. At the low frequency of 0,1 Hz, it is recommended to use Micro-Electro-Mechanical-Systems (MEMS) acceleration sensors, which can also be calibrated by means of acceleration due to gravity. ISO 16063-16

describes the calibration of the transmission coefficient at 0 Hz with reference to the local acceleration due to gravity.

To measure vibration, transducers shall be used which enable the entire measuring chain to meet the limits of the measurement frequency ranges as required in 4.5. For the measurement frequency range 0,1 Hz to 10 Hz, the vibration transducers shall be piezoelectric or micro electro-mechanical system (MEMS) capacitive accelerometers. With piezoelectric accelerometers, it is particularly important to ensure that the relevant rotor blade and structural frequencies have a sufficiently high separation to the lower 3 dB cut-off frequency of the transducer and ideally lie within the linear transmission range.

Other vibration transducers (e.g. electrodynamic vibration velocity transducers, piezoresistive accelerometers or fibre optic transducers) shall be evaluated regarding their suitability for use in wind turbine vibration measurement and calibrated in accordance with the requirements of ISO 2954.

Vibration velocity is usually determined using accelerometers. The accelerometer output signal shall be proportional to acceleration over the entire measurement frequency range and shall be integrated once to give the vibration velocity. The measurement uncertainty of the vibration velocity shall lie within the limits specified in this document. Reasons for measurement uncertainties are, e.g. pyroelectrical effects and specifying insufficient settling periods for the long integration periods needed in the low frequency range.

Accelerometers using piezoelectric elements as converters and, (instance e.g. built-in charge amplifiers with semiconductor components as converters) frequently have a limited working temperature range and caution shall be exercised when using them on a long-term basis for taking measurements on the hot parts of the wind turbine (e.g. gearboxes and bearings).

The measurements required for vibration evaluation can be taken using on-line or off-line systems. On-line systems are permanently installed in the wind turbine and automatically carry out data collection and characteristic quantity calculation and are used for continuous monitoring of the drive train condition as part of the overall condition monitoring system. Off-line systems are portable for periodic monitoring and used for taking short-duration measurements, being operated manually.

If on-line and off-line systems are used for evaluating wind turbine vibration, there shall be compliance with the characteristic vibration quantities for wind turbines, measuring positions, measuring directions and operating conditions given in this document when the measurement results are compared with the evaluation zone boundaries.

#### 4.4 Vibration transducer mounting and connection

Due to the width of the vibration spectra, the high levels of acceleration and the possible high temperatures at the measuring positions in the nacelle, connecting the transducers, can cause problems. The amplitude and frequency responses measured are influenced by how the transducers are attached. For advantages and disadvantages of the various methods used for mounting the transducers see ISO 5348.

Particularly where high frequency vibration responses are expected, the most rigid mounting method possible shall be used between the vibration transducer and its mounting. If holders are necessary to properly mount the transducer, they shall be as rigid as possible to avoid deviations occurring due to the natural frequency of the transducer and the holder system being excited. It can be necessary to check the rigidity of the transducer mounting by impact tests.

#### 4.5 Measurement and assessment of vibration quantities

##### 4.5.1 General

In all cases, the vibration acceleration and vibration velocity shall be evaluated. During the vibration measurement period, the wind speed, load and their variation shall be recorded. Acceleration captures the shock-shaped, high-frequency loads of structure-borne noise and low-frequency force impacts.