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Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts —

Part 21: Horizontal axis wind turbines with gearbox

Vibrations mécaniques — Évaluation des vibrations des machines par mesurages sur les parties non tournantes —

Partie 21: Turbines éoliennes à axe horizontal avec multiplicateur

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Contents

Page

Foreword

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary Information

The committee responsible for this document is 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*.

ISO 10816 consists of the following parts, under the general title *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts:*

- *Part 1: General guidelines*
- *Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*
- *Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured* in situ
- *Part 4: Gas turbine sets with fluid-film bearings*
- *Part 5: Machine sets in hydraulic power generating and pumping plants*
- *Part 6: Reciprocating machines with power ratings above 100 kW*
- *Part 7: Rotodynamic pumps for industrial applications, including measurements on rotating shafts*
- *Part 8: Reciprocating compressor systems*
- *Part 21: Horizontal axis wind turbines with gearbox*

A part 22 on horizontal axis wind turbines without gearbox is planned.

Introduction

Previous International Standards available for evaluating the vibration of structures and machines cannot be applied to wind turbines due to the special nature of their construction and operation. The vibration of the tower and nacelle of a wind turbine caused by the effects of wind, flow disturbances due to the tower (tower dam effect), the natural vibration of the rotor blades and structure itself (tower and foundation), and additionally, e.g. sea swell in the case of offshore wind turbines, differs from that of other industrial structures with respect to the time behaviour and spectra of the vibration.

ISO 10816-1, dealing with the measurement and evaluation of machine vibration, could be called on for the components of wind turbines (rotor bearing, gearbox, and generator). It is the basis of a number of other International Standards, including ISO 10816-3, for industrial machines of all kinds. Wind turbines are, however, expressly excluded from the scope of ISO 10816-3.

The criteria laid down in the other parts of ISO 10816 would, in principle, be applicable to wind turbine components. However, these criteria apply only to vibration generated within the machine set itself, and thus, affect its components directly. The criteria are also valid for evaluating the vibration emission (i.e. emission into the environment of a machine set), but they cannot be applied to vibration transmitted to the machines from external sources (i.e. vibration immission, structure-borne noise). With wind turbines, these are the effects of vibration of the tower or nacelle which are excited by wind and, in the case of offshore wind turbines, additionally by sea swell. Due to the extreme flexibility of blades and tower and the low rotor rotational speeds, it is necessary to include the low-frequency vibration in the measurement and evaluation.

The necessity to measure and evaluate the low-frequency vibration of the components in response to periodic and stochastic excitation sources requires modified evaluation quantities in contrast to ISO 10816-3 and this is complicated by the effects of wind and waves on the wind turbine structure which leads to high-amplitude, low-frequency vibration.

Due to the great influence of the vibration magnitude of a wind turbine on the stress of all components and thus on their operational reliability and service life, there is great interest of stakeholders involved in the manufacture, ownership operation, service, maintenance, and financing of wind turbines in having a recognized standard which provides criteria and recommendations regarding the measurement and evaluation of the mechanical vibration of wind turbines and their components. This is the central task of this part of ISO 10816 and a subsequent part 22 which is planned.

The aim of this part of ISO 10816 is to standardize measurements, to assist in their evaluation and to make possible a comparative evaluation of the vibration measured in wind turbines and their components. In the event of evaluation zone boundaries being exceeded, the results of such measurements should enable conclusions to be drawn regarding possible threats to the corresponding components of the wind turbine or to the installation as a whole, but without identifying the corresponding causes in any detail. If evaluation zone boundaries are not exceeded, the running behaviour can well be normal, but this does not rule out the possibility of individual instances of damage. Evaluation zone boundary values are not intended to be used as acceptance values. These need to be agreed on between the manufacturer and the user.

The working principle of wind turbines covered by this part of ISO 10816 is based on a rotating rotor with a horizontal rotational axis. The rotor consists of a rotor hub with rotor blades which are either mounted immovably or which can be turned on their longitudinal axis. The rotor hub is connected to the drive train of the wind turbine. The mechanical energy is converted into electrical energy by a generator which is driven via a gearbox or directly. As a rule, these energy conversion components are accommodated in a machinery housing which is referred to as the nacelle. The nacelle is mounted on bearings which allow it to rotate on the tower while the tower itself stands on its own foundation.

The rotor blades, and thus the rotor, are exposed not only to asymmetrically incoming air flow, but also to stochastic wind speed fluctuations. Asymmetric incoming flows are, for example, the result of wind turbulence, gusts, off-axis flow into the rotor, as well as different wind speeds distributed over the rotor surface. In addition to aerodynamic loads, the wind turbine is also affected by inertial forces and by loads resulting from different operating situations. Superimposition of the external conditions on the operating conditions such as power output and rotational speed, taking into consideration the constructive design of the wind turbine or its individual components, results in alternating loading on the entire wind turbine with its rotor, drive train, tower and foundation, and thus leads to vibration excitation at the individual components.

Drive trains consist of assemblies which are different in their type of design and their particular shafts. Therefore, they can excite vibration which is dependent or independent of rotational speed. Depending on the manufacturer and design, a different vibratory behaviour is shown by the generators, gearboxes and clutches, not only as individual assemblies, but also in interaction with, and depending on the type of wind turbine installation. Depending on the exciter and excitation range, the occurring vibration can, for example, result from poor alignment and lead to gear-tooth engagement shocks in the gearbox. Furthermore, resonance vibration can occur in the drive train. For these reasons, it is imperative in all cases to take the entire wind turbine into consideration, i.e. the drive train with rotor blades, nacelle, and tower.

On account of the great influence which the type of mechanical drive train can have on the vibration magnitude of all wind turbine components, it is necessary to divide the wind turbines into two groups:

— Group 1: horizontal axis wind turbine installations with generators coupled to the rotor via a gearbox;

— Group 2: horizontal axis wind turbine installations with generators coupled to the rotor without a gearbox (direct drive).

This part of ISO 10816 applies to group 1 wind turbines. A part 22 for group 2 wind turbines is planned and a limited amount of measured data is already available.

Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts —

Part 21: Horizontal axis wind turbines with gearbox

1 Scope

This part of ISO 10816 specifies the measurement and evaluation of mechanical vibration of wind turbines and their components by taking measurements on non-rotating parts. It applies to horizontal axis wind turbines with mechanical gearbox and rated generator output exceeding 200 kW and the following design and operational characteristics:

a) installation on supporting systems (tower and foundation) made of steel and/or concrete;

b) horizontal axis rotor with several rotor blades;

c) rotor bearing separate from or integrated into the gearbox;

d) generators driven via gearbox;

e) generators of the synchronous or asynchronous type (mostly equipped with 4-pole generator);

f) generators with only a fixed pole number or which are pole-changeable for speed adjustment;

g) output control by rotor blades (pitch or stall wind turbines);

h) generator coupled to the power grid via converter or directly.

This part of ISO 10816 recommends zones for evaluating the vibration at continuous load operation. However, in most cases, these evaluation zone boundaries might not be suitable for the early detection of faults. This part of ISO 10816 does not specify vibration values for the zone boundaries because there are insufficient data available for the complete range of wind turbines in the worldwide fleet covered by this part of ISO 10816. However, for information only, Annex A presents evaluation zone boundaries for onshore wind turbines. These zone boundaries are based on vibration data from about 1 000 wind turbines with rated generator output up to 3 MW. They can be helpful in facilitating discussion between users and manufacturers. Evaluation zone boundaries for offshore wind turbines are not yet available.

Although the type and implementation of broad-band vibration monitoring for wind turbines is addressed, this part of ISO 10816 does not apply to diagnostics or fault detection by condition monitoring of wind turbines.

NOTE 1 Information on condition monitoring and diagnostics of wind turbines will be given in ISO 16079 (all parts)[1].

The evaluation of the balance quality of the slowly turning wind turbine rotor, which requires special measurements and analysis, is not covered by this part of ISO 10816.

This part of ISO 10816 does not apply to the evaluation of torsional vibration in the drive train. Although coupled lateral and torsional vibration of tower and drive train can affect the amplitudes of the defined vibration characteristics, diagnosis of this kind of vibration source is not feasible by the described measurement methods described in this part of ISO 10816. For general design verification purposes and

1) To be published.

for specific fault diagnosis, special measurements are required which are beyond the scope of this part of ISO 10816.

NOTE 2 IEC/TS 61400–13 describes load measurement by use of strain gauges on the supporting structure and blades. Techniques to assist the detection of rolling element bearing and gearbox defects can be found in ISO 13373-2. Measurement and evaluation of structure-borne noise with rolling element bearings are given in VDI 3832.

This part of ISO 10816 does not also apply to acceptance measurements on gearboxes and generators in the manufacturer's test facility.

NOTE 3 These are assessed on the basis of appropriate standards namely ISO 8579-2 and IEC 60034–14.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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*

3 Terms and definitions

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

NOTE Special terms related to wind turbines are defined in IEC 60050–415. In this part of ISO 10816, for convenience, a wind turbine generator system (WTGS) is called simply a wind turbine (WT).

3.1
assessment acceleration
a_{w0}
broad-band r.m.s. value of acceleration in a given frequency band measured over a certain period of time

3.2
assessment velocity
v_{w0}
broad-band r.m.s. value of vibration velocity in a given frequency band measured over a certain period of time

4 Basic principles

4.1 Measurement and characteristic quantities

Characteristic quantities are formed by means of prescribed procedures from the raw measured signal (measured quantity). Measurements should be carried out at prescribed measuring positions, in specified measuring directions and under defined operating conditions. Exact measurement positions and directions may deviate from the recommendations provided in this part of ISO 10816 due to design of the housings or other access issues. Wind turbine manufacturers should provide transducer mounting positions appropriate to the aims of this part of ISO 10816. Procedures include the necessary signal processing, filtering, and averaging, as well as the formation of characteristic values or characteristic functions, and finally, displaying the results. This process is also referred to as the formation of characteristic quantities.

General information is provided in ISO 10816-1 and VDI 3839 part 1 regarding the measured and characteristic quantities used in this part of ISO 10816 as well as the procedures and instruments normally used for measuring and analysing machine vibration.

For the evaluation of the effects of vibration on wind turbines and their components, the machine vibration evaluation procedures mentioned in other standards or guidelines need to be supplemented to enable formation of the characteristic quantities.

4.2 Averaging methods and evaluation quantities for wind turbine vibration

The operating conditions applicable to wind turbines such as the continual changes in the strength and direction of the wind result in continually changing vibration excitations and, as a consequence of this, short-term changes in measured values with sudden variations in magnitude which are often considerable. Only seldom do such stable conditions occur for extended periods as are specified in the different parts of ISO 10816 for the evaluation of the vibration state.

For this reason, with wind turbines, it is absolutely essential when forming the characteristic quantities to average the measured values over specified time periods so as to compensate for any fluctuations. Before any comparison can be made against the evaluation zone boundaries (see Annex A), the values shall be based on comparably averaged data.

The averaging method chosen for wind turbines should be energy-equivalent averaging. Here, for example, from the measured acceleration in the time domain, an assessment acceleration a_{w0} is defined being a broad-band r.m.s. value. It characterizes the total loading over an evaluation period (which needs to be defined; see 4.3) and is obtained from the energy-equivalent mean value of the measured acceleration in a given frequency band in accordance with Formula (1):

$$a_{w0} = \sqrt{\frac{1}{T_0} \int_0^{T_0} a_w^2(t)\,dt} \qquad (1)$$

where

$a_w(t)$ is the acceleration in a given frequency band measured as a function of time;

T_0 is the evaluation period (see 4.3).

The frequency bands are specified in Clause 5. However, other frequency bands based on experience may be appropriate.

The assessment vibration velocity v_{w0} can be calculated in a similar way.

The evaluation of the vibration state is not only based on the assessment acceleration, but also on the assessment velocity.

NOTE The method described in this part of ISO 10816 for averaging the measured acceleration corresponds to that described in ISO 2631-1 when, for example, the long-term effect of vibration needs to be evaluated. The averaging method is formally the same as that described in ISO 8041 for obtaining the time-averaged r.m.s. value when the evaluation period T_0 is used for the time interval T defined there.

The evaluation period selected and the frequency bands used shall be indicated in all test records or reports together with the evaluation quantities concerned.

4.3 Evaluation period

The evaluation period, T_0, depends not only on the nature and time history of the effects on the entire installation and its components caused by wind, but also on the assessment quantity.

For the aerodynamically excited vibration of the nacelle, tower, and components with frequencies between 0,1 Hz and 10 Hz, and relatively high accelerations and velocities, the evaluation period should be set at 10 min. In this way even those vibration components with frequencies around or below 1 Hz (i.e. at the rotational frequency of the rotor) can be reliably measured and analysed.

At gearboxes and generators, characteristic design-related vibration with frequencies between 10 Hz and more than 1000 Hz can occur in addition. If evaluation is only to be concerned with these higher-frequency parts of the spectrum, shorter evaluation periods of, for example, 1 min, will suffice.

It might be necessary to subdivide the 10 min evaluation period into shorter time periods, T_e, which are determined by the measuring device or the operating conditions. If the vibration excitations change markedly during these time periods, this yields in each case different energy-equivalent mean values, a_{we}.

During any measurement interval, a record should be kept of the wind speed, load, and the variation thereof. This may be obtained retrospectively from the control system.

The assessment acceleration, a_{w0}, for the evaluation period, T_0, can be found from n shorter time periods, T_e, using Formula (2):

$$a_{\mathrm{w0}} = \sqrt{\frac{1}{T_0} \sum_{e=1}^{n} a_{\mathrm{we}}^2 T_e} \qquad (2)$$

where

$$T_0 = \sum_{e=1}^{n} T_e$$

5 Instructions on measurement and interpretation

5.1 General

In Clause 5, the characteristic quantities, measuring positions, and measuring directions are specified for the wind turbine as a structure and for its components.

Measurements should be taken on the bearing support housings or other structural parts which significantly respond to the dynamic forces and characterize the overall vibration of the machine. Typical measurement locations are shown in Figures B.1 and B.2. If the manufacturer has prepared suitable measuring positions to attach vibration transducers, these should preferably be used.

Although triaxial measurements at every measurement position would fully define the vibration of the machine, the full extent of measurement positions and directions may not always be necessary in order to keep the task of routine vibration verification manageable. Based on experience, the extent of the measurements may be reduced case by case by the parties involved.

Vibration measurement shall be made in units appropriate to the location.

In all cases, the vibration acceleration and the vibration velocity shall be evaluated. During any measurement interval, the wind speed, load, and the variation thereof should be documented.

5.2 Nacelle and tower

5.2.1 General

The vibration of the nacelle and tower of a wind turbine caused by the effects of wind, of flow disturbances due to the tower (tower dam effect), and of the natural vibration of the rotor blades and structure itself (tower and foundation) differ from those of other industrial structures with respect to the time behaviour and spectra of the vibration.

5.2.2 Characteristic quantities are the following r.m.s. values:

a) assessment acceleration, in m/s^2;

b) assessment velocity, in mm/s.

Both are formed in the frequency band 0,1 Hz to 10 Hz during the evaluation period specified in 4.3.

The lower limit of the frequency range (lower cut-off frequency) should normally set to 0,1 Hz. Only in the rare case that the wind turbine is operating at a rotor frequency below 0,1 Hz (6 r/min) during the evaluation period, the lower cut-off frequency shall be decreased below 0,1 Hz in such a way that the rotor spin frequency lies within the flat response region of the frequency band.

5.2.3 Typical measuring positions are

a) in the nacelle at the main frame close to the rotor main bearing,

b) on the structure above the tower flange, and

c) in the rear end of the nacelle on one side of the generator or main frame.

NOTE Figures B.1 and B.2 show, by way of example, the measuring positions on the structure (nacelle and tower).

5.2.4 Measuring directions are

a) axial (direction of the rotor shaft),

b) horizontal (transversely to the rotor shaft), and

c) vertical.

5.3 Rotor bearing

5.3.1 Characteristic quantities are the following r.m.s. values:

a) assessment acceleration, in m/s^2, formed in the frequency band 0,1 Hz to 10 Hz (for the lower cut-off frequency of 0,1 Hz, see the last paragraph in 5.2.2);

b) assessment velocity in mm/s formed in the frequency band 10 Hz to 1 000 Hz.

Both are formed during the evaluation period specified in 4.3.

5.3.2 Typical measuring positions are

a) for three-point suspension, on the housing of the front bearing (see e.g. Figure B.1), and

b) for two separate rotor bearings, on both bearing housings (see e.g. Figure B.2).

5.3.3 Measuring directions are

a) axial (direction of the rotor shaft),

b) horizontal (transversely to the rotor shaft), and

c) vertical.

5.4 Gearbox

5.4.1 Characteristic quantities are the following r.m.s. values:

a) assessment acceleration in m/s^2 formed in the two frequency bands 0,1 Hz to 10 Hz and 10 Hz to 2 000 Hz (for the lower cut-off frequency of 0,1 Hz, see the last paragraph in 5.2.2);

b) assessment velocity in mm/s formed in the frequency band 10 Hz to 1 000 Hz.

Both are formed during the evaluation period specified in 4.3.