INTERNATIONAL STANDARD

ISO 20283-4

First edition
2012-04-15

Mechanical vibration — Measurement of vibration on ships —

Part 4: Measurement and evaluation of vibration of the ship propulsion machinery

Vibrations mécaniques — Mesurage des vibrations à bord des navires —

Partie 4: Mesurage et évaluation des vibrations des machines de propulsion des navires

Reference number
ISO 20283-4:2012(E)

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Published in Switzerland

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 20283-4 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*.

ISO 20283 consists of the following parts, under the general title *Mechanical vibration — Measurement of vibration on ships*:

— *Part 2: Measurement of structural vibration*

— *Part 3: Pre-installation vibration measurement of shipboard equipment*

— *Part 4: Measurement and evaluation of vibration of the ship propulsion machinery*

The following part is planned:

— Part 1: General guidelines

Introduction

In general, classification societies ask for a numerical study on the torsional vibration behaviour of the propulsion system for seagoing vessels at the design stage as a base for the design approval. Depending on the results of this study and the kind of plant to be considered, further torsional vibration investigations for verification on a case-by-case study may be required. Explicit criteria for the evaluation of the torsional loadings are given within the rules of the international classification societies as well as in the form of unified requirements (UR) of the International Association of Classification Societies, specifically IACS UR M68,[10] with focus on the torque transmitting parts, such as shafts, gears, couplings, and connections. Studies of the bending vibration behaviour of the shaft as well as axial vibration of the propulsion system or crankshaft may be required by the classification societies in the exceptional case that the special design of the system makes such additional investigations necessary.

Propulsion systems may be exposed to vibration of high magnitude in general excited by the engine and/or propeller. In addition to the numerical criteria for evaluation of torsional vibration, some further special requirements may be raised, such as avoiding load reversal in the transmission train. In general, mechanical components may be perfectly designed for load reversal operation; however, some specific requirements in this direction are also based on smooth operation of the plant, and the owners or managers of special vessels such as navy ships or yachts consequently raise them.

The user of this part of ISO 20283 should bear in mind that for the evaluation of measured data on propulsion plants of ships the rules of the responsible classification society for the vessel in their latest edition or the valid IACS UR should be considered.

Should any issues regarding this part of ISO 20283 be directly or indirectly addressed by the contracted classification society's rules or other international binding regulations, such as those of the International Maritime Organization (IMO), the International Convention for the Safety of Life at Sea, and UK Maritime and Coastguard Agency, the choice of the measuring method applied should fulfil the sense of these rules or regulations, independently of whether the special measuring method is specified within this part of ISO 20283.

Mechanical vibration — Measurement of vibration on ships —

Part 4:
Measurement and evaluation of vibration of the ship propulsion machinery

1 Scope

This part of ISO 20283 provides guidelines for the instrumentation, measurement, and data processing procedures required to obtain reliable vibration data on ship propulsion systems. It also gives guidelines for the application of specific measuring techniques, which are common and adequate for measuring the mechanical vibration on propulsion plants of seagoing and inland vessels. The measuring techniques can be applied to diesel engine as well as turbine or electrically driven plants, always considering the specific limitation of application of each individually described procedure.

The procedures specified in this part of ISO 20283 focus on repetitive mechanical vibration (steady-state or quasi-stationary like a sweep) and can therefore be inadequate for measuring and evaluating transient, very fast-changing or shock signals.

This part of ISO 20283 mainly specifies techniques for measuring the mechanical vibration of the main propulsion plant during sea trials. The same or similar measuring principles can also be used for other purposes, such as performance monitoring, investigations of abnormal vibration in service, and evaluation of the condition of repaired parts. However, in such cases, the measuring procedure needs to be adapted to the specific requirements.

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 2041:2009, *Mechanical vibration, shock and condition monitoring — Vocabulary*

3 Terms and definitions

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

3.1
free route
condition achieved when the ship is proceeding at a constant speed and course with helm adjustment of ±2° or less and no throttle adjustment

[SOURCE: ISO 20283-2:2008, 3.3]

3.2
vibration severity
value, or set of value, such as maximum value, average or r.m.s. value, or other parameters that are descriptive of the vibration, referring to instantaneous values or to average values

[SOURCE: ISO 2041:2009, 2.51]

Note 1 to entry: The vibration severity is a generic term, which in the past has been used in relation to vibration velocity. However, it is now more generally used as descriptive of other measurement units, such as displacement and acceleration.

3.3
peak value
maximum value of a vibration during a specified time interval

[SOURCE: ISO 2041:2009, 2.44]

Note 1 to entry: A peak value is usually taken as the maximum deviation of that vibration from the mean value. A positive peak value is the maximum positive deviation and a negative peak value is the maximum negative deviation, see Figure 1.

Note 2 to entry : In vibration, usually the peak value is understood as half of the peak-to-peak value (of a vibration) since positive and negative peak values can be different, see also 3.4.

3.4
peak-to-peak value
⟨vibration⟩ difference between the maximum positive and maximum negative values of a vibration during a specified interval

[SOURCE: ISO 2041:2009, 2.45]

Note 1 to entry: See Figure 1.

3.5
r.m.s. value
⟨vibration⟩ root mean square value (computed by the square root of the sum of the squares of the magnitude) of a fast Fourier transform spectrum with a defined bandwidth or of a time signal during a specified time interval (e.g. a period of the fundamental frequency)

EXAMPLE 1 An r.m.s. value within a time interval t_1 to t_2

$$\sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} u^2(t)\,\mathrm{d}t}$$

EXAMPLE 2 An r.m.s. value from a fast Fourier transform (FFT) spectrum with N spectral lines

$$\sqrt{\frac{1}{2}\sum_{n=1}^{N} X_n^2}$$

See Figure 1.

Note 1 to entry: This definition of r.m.s. value of a spectrum is derived from the more general definition of r.m.s. spectrum in ISO 2041:2009, 5.11, adapted to the common use in vibration.

Note 2 to entry: For sine waves, the r.m.s. value is the peak value divided by √2.

Note 3 to entry: In case of mixed source excitation, windowing should be applied. Additional factors need to be included, to give an r.m.s. value of the form:

$$\sqrt{\frac{1}{2B}\sum_{n=1}^{N} X_n^2}$$

where

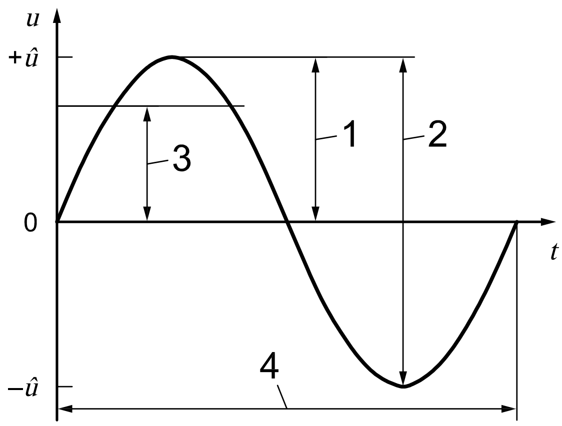
B is the window noise bandwidth factor depending on the anti-leakage window:

$B = 1{,}5$ for a Hanning window,

$B = 3{,}77$ for a flat top window,

$B = 1$ without an anti-leakage window;

X_n is the narrow band magnitude obtained by FFT.



Key

1 peak value, $\hat{u}$

2 peak-to-peak value, from $-\hat{u}$ to $+\hat{u}$

3 r.m.s. value

4 period duration

Figure 1 — Values of a vibration $u(t)$ (simplified for a sine wave)

4 Vibration tests

4.1 Instrumentation

The transducers, the signal conditioning, and data storage equipment shall be capable of performing accurate measurements in the frequency range, which is adequate for the vibration quantities to be measured. The applied measurement techniques should be able to maintain an accuracy of ±10 %. The involved parties, namely the yard or builder, owner, class, and supplier, should define a suitable frequency range for the measurements, depending on the mechanical quantity to be measured. As a general guideline, for linear vibration measurements, an upper frequency limit of 1 000 Hz is normally used and sufficient. For strain gauge measurements of forces or torques or other measurements on the rotating parts of the propulsion system, an upper frequency limit of 100 Hz for low-speed two-stroke engines and of 400 Hz for four-stroke engines is sufficient (for four-stroke engines at least the upper frequency has to come up to the product of maximum rotational speed by number of cylinders). For acceleration measurements on gearboxes, higher frequencies, depending on the excitation forces (gear mesh frequencies), can be appropriate.

The raw or processed data shall be stored permanently by electronic means. Paper printouts may be acceptable in some cases, but for reproduction purposes, electronic (analogue or digital) data storage is preferred. The complete transfer function of the measuring chain from transducer to storage and playback equipment or its playback digital data shall be known to the operator and validated on site or in the laboratory.

It is recommended that the phase of the measured vibration be registered in reference to the source of the excitation, i.e. a marker indicating the absolute position of the main excitation source should be provided. This is commonly a marker indicating the phase of the engine (e.g. TDC 1 = top dead centre, cylinder No. 1), but also the phase of the propeller can be of significance in some exceptional cases.

4.2 Test conditions

Certain sets of measurements concerning the propulsion system require steady-state conditions and refer to specified loading conditions for the ship in order to fulfil repeatability expectations, such as the following.

a) Ship loading condition should be as close as possible to the contracted nominal operating condition. This condition is at least the ballasted condition of the ship, which is common during sea trials, with a fully submerged propeller.

b) Water depth should be not less than five times the draught of the ship. Deviations shall be agreed by the contractors and stated in the report.

c) Minimum turning to maintain course during the free-route test should be achieved. The rudder angle should be restricted to about 2° port and starboard.

d) Maximum sea state should be as follows, with no slamming or severe wave impacts, specifically:

   small craft: sea state 1;

   small ships (<100 m): sea state 2;

   large ships (≥100 m): sea state 3.

e) The engine should work under normal operating conditions. For some kinds of measurements and certain plants, additional measurements with specified deviations from the normal operation condition may be agreed upon (typically, this is the misfiring or cylinder cut-off condition for torsional vibration).

f) For more complicated plants including multiple engines, shafts and clutches, the kinds of operational modes to be investigated shall be agreed upon between the involved parties before performance of measurements. In this respect, it can be obligatory to fulfil requirements of classification societies (e.g. torsional vibration for one- and two-engine operation if two engines are working via clutches on one shaft, or normal and emergency operation for ships with redundant propulsion class annotation).

4.3 Test procedure

4.3.1 General

Each measurement channel shall be checked in an adequate way for reliable, repeatable and accurate operation. Strain gauges are normally to be calibrated electrically after installation on site.

If it is agreed to evaluate the types of measured mechanical vibration (torsional, bending, axial, transversal) in reference to each other (instead of estimating the magnitude of each type only), it is recommended that either simultaneous multi-channel storage techniques be used or additionally the phase of the individual channels be stored.

4.3.2 Steady-state measurements

Acquisition of “steady-state vibration data” under the conditions specified in 4.2 may be performed by one of the following procedures.

a) Registration of steady-state values during constantly set speed steps uniformly distributed over the entire available speed range between minimum and nominal (maximum speed). The number of steps shall be such that the vibration behaviour over the speed range can be recorded accurately in accordance to the needs described [for guidance: distance of steps equal to about 5 % intervals of the nominal speed, in the nearest vicinity of resonances a continuous slow run up (or run down) as specified in b) or smaller steps are favourable].

b) Slow and steady acceleration from minimum to nominal (maximum) speed. The run up shall be slow enough to enable full development of the vibration quantities to be measured. In exceptional cases, deceleration (run down) of the plant may also be considered; however, maximum excitation is expected during acceleration [for guidance: apply an acceleration of <2 % of the nominal speed value per minute which results in about 30 min per run up (or run down) for a direct coupled two-stroke engine. For medium- and high-speed four-stroke engines, an acceleration of <15 % of the nominal speed value per minute which results in about 10 min per run up (or run down) shall be applied].

It is recommended that the acceleration of the engine and vessel be such that the power absorption curve follows the nominal power-speed curve.

In exceptional cases, manoeuvring or transient measurements according to Annex A may be applied.

4.4 Data processing

4.4.1 General

Magnitudes versus frequency or harmonic order spectra are recommended. A resolution of at least 400 spectral lines and a Hanning window are often used, but different parameters may be more appropriate for better amplitude or frequency resolution (e.g. 1 600 spectral lines resolution, flat top window, 1 kHz frequency range). Spectra should be averaged over the length of the data record. The spectra should be used in generating plots of the amplitudes of all major shaft rotation orders (major engine excited harmonic orders, shaft rate, blade rate), mostly plus the resulting values (see 4.4.2) versus rotational shaft speed.

Alternatively, order tracking can be applied, if the excitation is mainly periodic with shaft or engine revolutions. Order tracking is a procedure with a measurement period per timeframe that is adjusted continuously to one base excitation cycle, i.e. one revolution for two-stroke or two revolutions for four-stroke reciprocating engines). Then the corresponding order spectra or order plots versus shaft speed generally do not need windowing or high spectral resolution.

4.4.2 Vibration severity

Either values for vibration severity (often also called resulting values) shall be obtained as peak values or as r.m.s. values, depending on the parameter measured (see 4.4.3).

Commonly averaged FFT are used at constant-speed measurements, and single FFT in measurements at variable speed.

The frequency or order range for this evaluation can be restricted to an appropriate range for each measurement parameter. If any post-processing like filtering is applied, e.g. due to excessive signal noise or other high- or low-frequency signal disturbance, this shall be stated. Then the vibration severity can be evaluated directly from the filtered signal or by calculating it from the reduced number of frequency or order values, with their phases in case of peak values.

4.4.3 Quantities of interest

For measurements on rotating parts of the machinery (e.g. alternating torque or thrust and alternating torsional or bending stress), the peak values per cycle are of interest and shall be displayed in the graphic diagrams. The values can be scaled as absolute values or as percentage of the nominal (or design) thrust and torque. The curve representing the measured (or theoretical) mean value of the torque or thrust can be added to the diagram in order to visualize possible torque or thrust reversals.

NOTE If the alternating thrust is greater than the mean thrust, the thrust changes direction from ahead to astern with the frequency of the superimposed dynamic thrust. Likewise, if the alternating torque for geared plants exceeds the mean torque, audible hammering of the gear’s teeth occurs. These conditions are calculated or evaluated during design approval. Load reversal can be an allowable operation especially in the lowest speed range.

For linear vibration measurements, the r.m.s. value from the FFT normally is taken as the relevant vibration severity. This applies to linear acceleration or velocity on non-rotating parts of components of the propulsion train as listed under 4.5.5. Additionally the highest spectral amplitude is also an important indicator.

In addition, the single amplitudes of the relevant shaft rotation orders (major engine excited harmonic orders, shaft rate, blade rate) can be included when plotted against rotational shaft speed for visualizing the resonances of the propulsion system.

4.5 Measurements

4.5.1 General

The extent of measurements is subject to specific agreement between the interested parties.