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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

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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

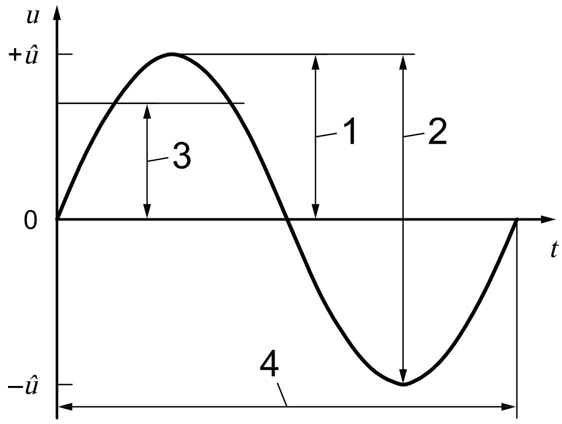
B is the window noise bandwidth factor depending on the anti-leakage window:

$B = 1{,}5$ 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.

Some of the measurement methods provide values that cannot be used for direct assessment; therefore, they need to be recalculated by means of a mathematical model, which shall be agreed by the interested parties and reported.

4.5.2 Torsional vibration measurements of the shafting system

Prior to a measurement, normally a torsional vibration calculation is performed and this calculation shall be agreed by the interested parties (e.g. classification society, manufacturer, consultants, owners).

Measurements shall be carried out by applying appropriate measuring techniques (see the basic alternatives as given in the following). Measurements should be made as close as practical to where the measured quantity is representative for all vibration modes of concern.

For assessment, the measured quantities should be transformed by the accepted torsional vibration calculation model into the appropriate parameters (such as alternating torques or stresses at other parts of the system for which evaluation of the torques or forces is of interest). Typically, such components are elastic couplings, gear meshes, connections (alternating torques) as well as shafts (alternating shear stresses).

Measurement techniques can be one of the following:

— dynamic stress measurements by strain gauges;

— measuring the torsional vibration angular or twisting amplitudes by encoders or other angular measurement methods.

4.5.3 Axial vibration measurements of the shaft

Axial vibration measurements are carried out if they are agreed by the interested parties (e.g. classification society, manufacturer, consultants, owners).

Measurements shall be carried out by applying appropriate measuring techniques (see the basic alternatives as given in the following). Measurements should be made as close as practical to where the measured quantity is representative for all vibration modes of concern.

If the relevant parameter is not directly measured, then for assessment the measured quantities should be transformed into the appropriate parameters by the accepted calculation model.

Measurement techniques can be one of the following:

a) axial movement or vibration of shaft:

  — movement of flanges against the corresponding bearing housing or foundation;

b) thrust (force) measurements (see Note 3):

  — dynamic longitudinal stress measurement by strain gauges on the shaft,

  — instrumented thrust collar,

  — movements of thrust bearing and recalculation of thrust by means of stiffness model of bearing,

  — bending stresses on non-rotating parts of thrust bearing and recalculation of thrust by means of model of bearing.

NOTE 1 Axial vibration measurements are usually taken only in cases of specific technical necessity.

NOTE 2 For large two-stroke diesel engines, measurements are usually taken at the free end of the crankshaft.

NOTE 3 Thrust (force) measurements at the thrust bearing apply in exceptional cases only (e.g. special vessels or investigation of damages), i.e. they are not applicable for large two-stroke diesel engines and for geared propulsion plants with thrust bearings integrated into the gearbox housing.

4.5.4 Bending (whirling) vibration measurements of the shafting

Bending (whirling) vibration measurements are carried out if it is agreed by the involved parties (e.g. classification society, manufacturer, consultants, owners).

Measurements shall be carried out by applying appropriate measuring techniques (see the basic alternatives as given in the following). Measurements should be taken as close as practical to where the measured quantity is representative for all vibration modes of concern.

If the relevant parameter is not directly measured, then for assessment the measured quantities should be transformed into the appropriate parameters by the accepted calculation model.

Measurement techniques can be one of the following:

— bending stress measurement by strain gauges;

— travel of shaft by 90° (orthogonal) lateral probes.

NOTE Bending (whirling) measurements apply in occasional cases only (e.g. if the calculation shows natural frequencies close to main excitation frequencies of this vibration). Measuring the bending vibration can gain technical significance especially for fast rotating shafts of smaller diameters and increased bearing distances and in cases of forced introduction of high vibratory bending moments as is typical for fast rotating cardan shafts with high inclination.

For bending (whirling) vibration measurements, two full measurement bridges at 90° are needed to evaluate the true dynamic bending stress.

4.5.5 Measurements of linear or lateral vibration of non-rotating parts of machines and components

4.5.5.1 General

Linear (structure) vibration measurements are usually taken with accelerometers or velocity transducers.

With the vibration measurement on board, both internally excited vibration and externally imposed vibration are measured.

The test conditions are according to 4.2. The test programme is to be defined by the interested parties.

The most significant positions are dependent on the type of installation and shall be agreed by the interested parties prior to the measurements.

Those measurements may include the components in 4.5.5.2 to 4.5.5.8.

4.5.5.2 Diesel engines

4.5.5.2.1 General

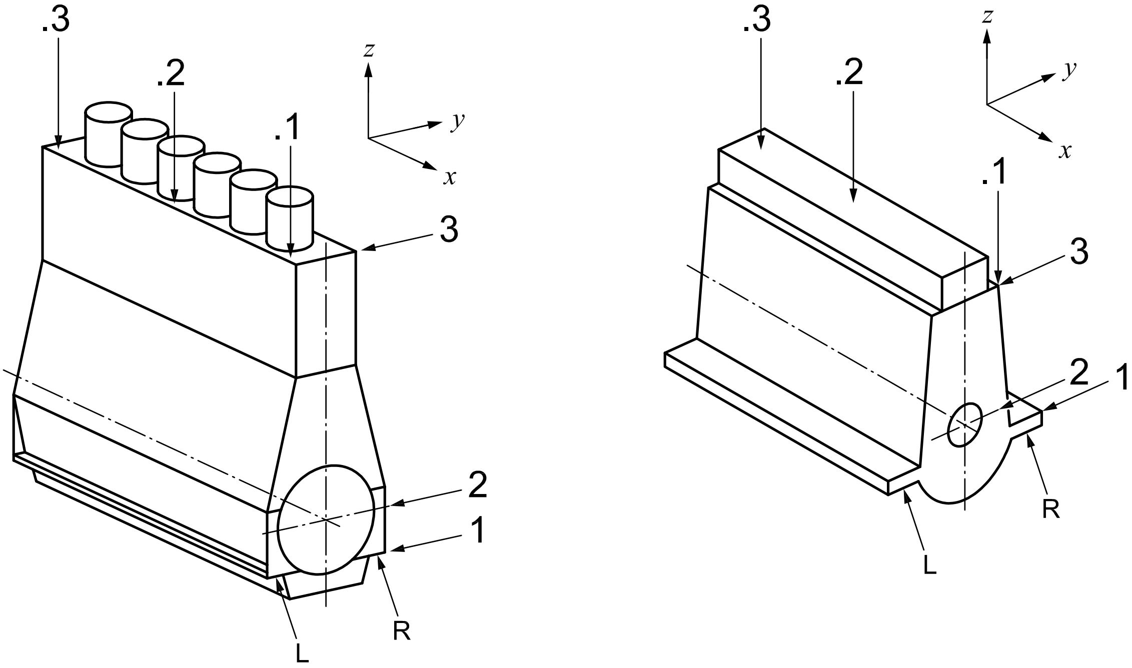
For definition of measurement points as well as for the evaluation of the measuring data, the kind of mounting (elastic or rigid) of the engine shall be considered.

Marine diesel engines are, as a rule, type-approved components, and as such, they are designed to withstand certain levels of vibration and the relevant criteria for assessment of measured vibrations are given by the engine manufacturers, most often as maximum values referred to level 3 (top edge of frame, see Figure 2). Sometimes, manufacturers also give a range for typical values for a certain kind and application of an engine.

However, admissible values provided by engine manufacturers are usually given for the main purpose of not compromising the engine's integrity and function in the long term. For this reason, acceptable vibration levels at level 1 (machine end of mounting on foundation, see Figure 2) of rigidly mounted engines shall take into consideration the requirements on the ship hull side (transmitted dynamic forces, vibration and noise). Therefore, they should be substantially lower than the values that are normally accepted at level 3 (typically less than half, dependent on the direction and the method of mounting). This applies specifically not only to the majority of slow-speed two-stroke engines (see 4.5.5.2.2), but also to rigidly mounted four-stroke engines.

Elastic (resilient) mounting generally applies to medium- and high-speed engines. The measurement data on the frames of such engines as well as for the appended parts are a mixture of direct engine (gas or mass) forces and the movements of the engine on the resilient mounting. Commonly, these influences should be evaluated separately. The requirements of low introduced dynamic forces, vibration, and noise on the ship hull side are usually fulfilled by an appropriate design of the resilient mounting system. Thus, the vibration levels below the resilient mounts are typically much lower than the corresponding engine vibration, see 4.5.5.2.3.

Typical measurement points and definitions of nomenclature for the vibration are given in ISO 10816-1 and ISO 10816-6; see Figure 2. These may apply, if the engine manufacturer does not indicate measurement points.



a) Low-speed two-stroke engine **b) Four-stroke engine**

Key

Sides:	L	left-hand when facing drive end flange	Longitudinal position:	.1	drive end (DE) of machine
	R	right-hand when facing drive end flange		.2	mid-machine
				.3	non-drive end (NDE)
Levels:	1	machine end of mounting			
	2	crankshaft level	Directions:	*x*	longitudinal
	3	top edge of frame		*y*	transversal
				z	vertical

Figure 2 — Typical measurement points on a diesel engine

4.5.5.2.2 Considerations specific to linear vibration of two-stroke diesel engines

Direct-coupled marine diesel engines are typically two-stroke engines working at nominal rotational speeds between 70 r/min and 250 r/min. Such engines are in their majority rigidly connected to the ship's structures or foundation by steel bolts. Therefore, the vibration level, especially in the vicinity of the foundation, depends highly on the design of this foundation and the natural frequency of the combined structure which consists of the engine being connected to the foundation and ship's structure by steel chocks or cast resin.

As a guideline, ISO 10816-6:1995, Table A.1, together with the following instructions may apply, if the engine manufacturer gives no specific criteria for assessment.

For the determination of the r.m.s. vibration magnitude, the frequency range should be limited to 1 Hz to 100 Hz, and local resonance effects shall be excluded from this by using appropriate filtering, this differs from ISO 10816-6:1995, 4.1 and Clause 5.

For engine frame vibration (measurement points according to ISO 10816-6:1995, 4.2, level 3), a maximum value (for the *machine vibration classification number*) equal to 5 (vibration severity grade 28) is applicable as an initial guideline.

Higher values may be acceptable depending on the engine manufacturer's or component supplier's specifications.

For the vibration of mounted components (e.g. turbochargers, charge air coolers, engine control components) the vibration limit values agreed as permissible between the manufacturer of the mounted components and the manufacturer of the reciprocating machine apply, as do the specified frequency ranges and measuring positions.

The vibration of major attached structures (platforms, exhaust manifolds, etc.) shall be considered as local vibration and cannot be assessed by these guideline values. Normally, the engine manufacturer as the designer of those components gives assessment criteria for this vibration. The vibration of minor attached structures (e.g. platform floor plates, handrails, pipes) is often characterized by additional local resonances and is therefore subject to separate considerations.

Mounted (often subcontractor) components such as turbochargers and charge air coolers are commonly designed and type approved for certain levels of vibration, depending on their application. In general, these limits should be applied for evaluation purposes, since the design is adequate for that and the qualification has been carried out for this specific level of vibration.

NOTE 1 The values in the preceding are not considered binding limits since ISO 10816-6 is applicable to machines with nominal rotational speeds above 250 r/min only.

NOTE 2 ISO 10816-6:1995, Figure C.1 is not at all suited to large two-stroke engines, since the crossover frequencies of 10 Hz and 250 Hz do not reflect the influence of the comparatively low engine speed and the influence of the correspondingly low frequencies. Therefore that figure cannot be applied to these engines.

4.5.5.2.3 Considerations specific to linear vibration of four-stroke medium- and high-speed engines

Four-stroke engines for marine applications cover a rotational speed range between 300 r/min and 2 500 r/min; the lower speeds are appropriate for larger medium-speed engines, the upper to compact high-speed engines. Typically, such engines are connected via a gearbox to the propeller shaft and are in their majority resiliently mounted.

For rigidly mounted four-stroke engines, the interaction of engine, foundation, and ship is comparable to that described for two-stroke engines in 4.5.5.2.2, in addition to the general considerations given in 4.5.5.2.1 regarding acceptable vibration on level 1. That is, not only should the admissible values for the engine be considered, but also care shall be taken that the transmitted dynamic forces to the ship hull side remain in an acceptable range.

Resiliently mounted engines typically have a higher vibration level because their vibration includes additional low-frequency components, and the dynamic forces transmitted to the ship hull are much reduced by the resilient elements. Therefore, admissible values — referred to the engine on level 1 (machine end of mounting on foundation, see Figure 2) — are also higher. Consequently, acceptable values are directly comparable to those given by the manufacturers for level 3 (top edge of frame).

As a guideline, ISO 10816-6:1995 together with the following instructions may apply, if the engine manufacturer gives no specific criteria for assessment.

Taking the above into account, for engine frame vibration (measurement points according to ISO 10816-6:1995, 4.2, level 1), a maximum value (for the *machine vibration classification number*) equal to 6 (vibration severity grade 45) for elastically (resiliently) mounted medium and high-speed four-stroke engines and a maximum value equal to 5 (vibration severity grade 28) for rigidly mounted four-stroke engines is applicable as a first guidance. Measurements at level 3 ("top edge of frame") of four-stroke engines may be difficult in practice due to limited access or lack of a well-defined position and to the fact that this vibration often contains high-frequency components if measured on the cylinder heads.

Higher values may be acceptable depending on the engine manufacturer's specifications. Especially resiliently mounted high-output high-speed engines can be designed to accept considerably larger vibrations.

See also ISO 10816-6:1995, Table A.1.

Vibration of mounted components (e.g. exhaust manifolds, charge air coolers, handrails, pipes) is to be considered as local vibration and cannot be assessed by this guide value. The vibration limit values agreed as permissible between the manufacturer of the mounted components and the manufacturer of the reciprocating machine apply, as do the specified frequency ranges and measuring positions.

Mounted components, such as coolers, manifolds, and turbochargers, are commonly designed and type approved for certain levels of vibration, depending on their application. In general, these limits should be applied for evaluation purposes, since the design is adequate for that and the qualification has been carried out for this specific level of vibration.

4.5.5.3 Gas turbines

As a guideline for marine application gas turbines, ISO 10816-3 and ISO 10816-4 may apply, if the gas turbine manufacturer gives no indication for measurement points and no criteria for assessment.

For measurements of gas turbines as a prime mover, vibrations generated by the gas turbine itself and those vibrations that are introduced to the manifold by the marine environment (such as propeller-excited vibration) should be clearly distinguished. Typically, the design values are applied to the vibrations generated by the gas turbine, and the measurement fulfils an aim similar to the "online monitoring" of the gas turbine itself. Typical values for such measurements are the unbalance (1st order, 2nd order radial) of the rotor(s) as well as the axial travel of the shafts. For correct evaluation of such measurements, reference should be made to the design values that have been derived within the qualification process.

NOTE For vibration introduced by the marine environment to the gas turbine unit, most manufacturers consider no r.m.s. velocity values higher than 14 mm/s. However, some commercial gas turbine units are designed to withstand shocks and in general higher vibration values.

Exhaust gas turbochargers are also a special kind of gas turbine. Since turbochargers are mounted on the engine, they can be regarded as "appended parts". However, as a rule, such manifolds are designed for this purpose and they can work reliably under heavy vibration conditions. Reference should be made to the vibration magnitude that has been considered at type approval. The manufacturers give typical admissible values for turbochargers as a "total admissible vibratory acceleration", e.g. ± 25 m/s^2. Such values refer to the gas and mass forces introduced by the engine, amplified by the turbocharger's foundation on the engine. They need to be clearly distinguished from the "internal unbalance" of the turbocharger. Monitoring systems of turbochargers typically focus on the "internal unbalances" and work, as a rule, by case-dedicated filtering techniques. Such signals are not adequate for evaluation of the turbocharger's overall vibration.

4.5.5.4 Steam turbines

As a guideline for marine application steam turbines, ISO 10816-2 and ISO 10816-3 may apply, if the steam turbine manufacturer gives no indication for measurement points and no criteria for assessment.

For measurements of steam turbines as a prime mover, vibrations generated by the steam turbine itself and those vibrations that are introduced to the manifold by the marine environment (such as propeller-excited vibration) should be clearly distinguished. For the vibrations generated by the steam turbine itself, typically the design values are applied and the measurement fulfils an aim similar to "online monitoring". Typical values for such measurements are the unbalance (1st order, 2nd order radial) of the rotor(s) as well as the axial travel of the shafts. For correct evaluation of such measurements, reference should be made to the design values, which have been derived within the qualification process.

NOTE 1 For vibration introduced by the marine environment to the steam turbine unit, most manufacturers consider no r.m.s. velocity values higher than 14 mm/s.

NOTE 2 Smaller steam turbines are also applied for production of electrical energy using the exhaust gas of the main engine(s). Such manifolds are mounted on a separate frame and have been, as a rule, qualified for the zone A limit in accordance with ISO 10816-1:1995. For special applications, such as direct mounting on the engine, the manufacturer needs to qualify the units for the appropriate higher vibration values.

Two- (split) shaft steam turbines for propulsion transmit their power via a two-input shaft gearbox. The gearbox itself as well as the other process units needs to be evaluated separately, by the limits for which they have been qualified. They cannot be regarded in this respect as an integral part of the steam turbine itself.

4.5.5.5 Electric propulsion motors

As a guideline for marine application electrical propulsion motors, ISO 10816-3 may apply, if the electrical motor manufacturer gives no indication for measurement points and no criteria for assessment.

For measurements of electrical propulsion motors as a prime mover, vibrations generated by the electric motor itself and those vibrations that are introduced to the manifold by the marine environment (such as propeller-excited vibration) should be clearly distinguished. For the vibrations generated by the electric motor itself, typically the design values have to be applied. Those vibrations are caused by unbalances of the rotor as well as irregularities of the magnetic field and can be measured on a test bed, where the influences of the marine environment do not exist. Typical r.m.s. velocity values are considerably less than 5 mm/s (admissible unbalance). In connection with the systems of a ship and the direct coupling to the propeller shaft, another spectrum of vibration arises.

NOTE For vibration introduced by the marine environment to the electric motor, most manufacturers consider no r.m.s. velocity values higher than 14 mm/s. However, designs adequate for higher vibration levels are available.

The first order (revolutions) vibration cannot only be excited by the internal unbalance of the motor (see the preceding) but also, mainly, by the connected shaft and the alignment. These two kinds of vibration need to be distinguished: the first part should remain within the design specified r.m.s. velocity values (typically less than 5 mm/s); for the second part the internal design and qualification of the motor is applicable. Commonly zone B as defined in ISO 10816-1:1995 is applied for this second part of first order vibration.

For other electrical machines, such as shaft generators, the suitability of the applied bearings can be the main limiting criterion. In such cases, the design and suitability of the bearings for a high vibration level should be considered.

4.5.5.6 Gearboxes

Measurements of linear vibration of gearboxes are an indirect method of estimating loads within the gearbox. Those vibrations can be caused by external as well as internal sources.

Typical internally produced vibrations are the “footprint” of the gear meshes, roller bearings as well as the “unbalance” vibration of input, output and intermediate shafts.

Typical externally produced vibrations include those from the engine, propeller, and alignment.

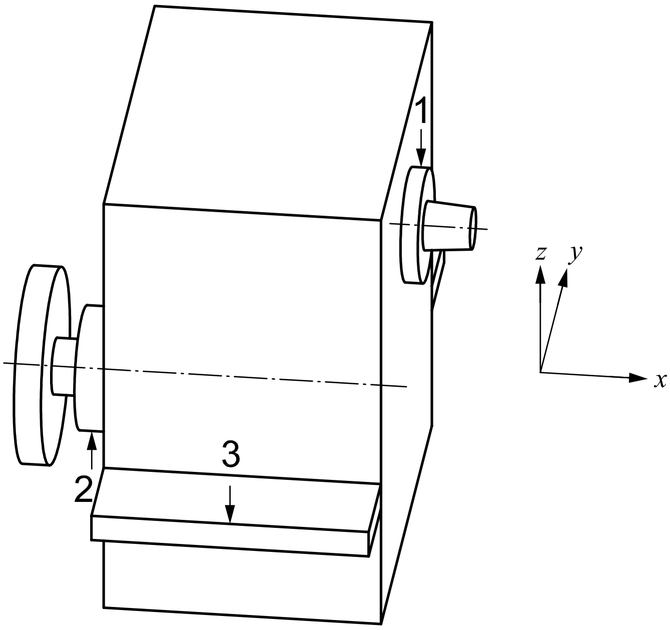
The sources of vibration mentioned shall be clearly distinguished. Especially gear mesh-induced accelerations measured on the casing of gearboxes are located in the upper frequency range and have small amplitudes in comparison to the overall synthesized values, which are dominated by vibration generated by the marine environment. Filtering techniques may prove to be indispensable for proper evaluation.

The measurement should extend over the complete operational speed range of the installation. The fact that within operational speed ranges the components attached to the gearbox do not fall into a resonance with the main excitation orders of diesel engine or propeller should be taken into consideration.

The vibration magnitude should be measured in the frequency range 2 Hz to 1 000 Hz.

Since it is hard to achieve an accurate estimation of gearbox loads based on vibration data, the vibration level should be kept low. The allowable vibration level depends on many factors, e.g. gearbox type and size, engine type, application, housing material, foundation hull type, measuring position, and source of vibration. Thus, it is not possible to have one general vibration limit.

The vibration specification of the gearbox manufacturer should be followed. The interested parties may agree to special vibration specification. A typical range of these specifications for an operation of separately mounted gearboxes driven by diesel engines is described in the following for information. Typically the specifications apply to the three main directions of motion — vertical, transversal, longitudinal — under operating conditions. Typical measurement points are specified in Figure 3. The gearbox manufacturer may indicate different measurements points to which their vibration limits are adapted.



Key

1 bearing cover gearbox propulsion input shaft

2 bearing cover gearbox propulsion output shaft

3 gearbox brackets

Figure 3 — Typical measurement points for marine gearboxes

The typical goal of the vibration specification is to ensure the mechanical reliability of the gearbox. Comfort aspects as well as the requirements of classification societies lie outside the scope of this part of ISO 20283, but may be considered as separate criteria.

It should again be noted that the vibration recommendations or requirements of the gearbox manufacturer or the involved parties do not refer to an arbitrary severity grade, but to one explicit severity grade only. This depends on the factors mentioned in the preceding. If no specification is available, the lowest values should apply.

A typical acceptable value for continuous long-term operation (zones A and B) could be not only vibration severity grade 7 but also 11 or 18 (see ISO 10816-6:1995) depending on the specification.

A typical acceptable value for limited operation time (zone C) could be not only vibration severity grade 11 but also 18 or 28 (see ISO 10816-6:1995) depending on the specification. This class may also acceptable for the operation of vessels with low operation time (e.g. yachts).

To determine whether vibration values are dominated by one order only, the highest peak value of the FFT spectrum should be checked. A typical acceptable value for such single peaks could be not only 7 mm/s but also 11 mm/s or 18 mm/s depending on the specification.

If the vibration limitations are exceeded, the manufacturer shall be informed accordingly. In special cases, the gearbox manufacturer may allow higher limiting values. This can only be done by considering the detailed vibration report.

Overhanging housing designs featuring elastic bearing brackets, i.e. the first bearing of lightweight gas turbine gearboxes, may have higher allowable values depending on the manufacturer's consideration.

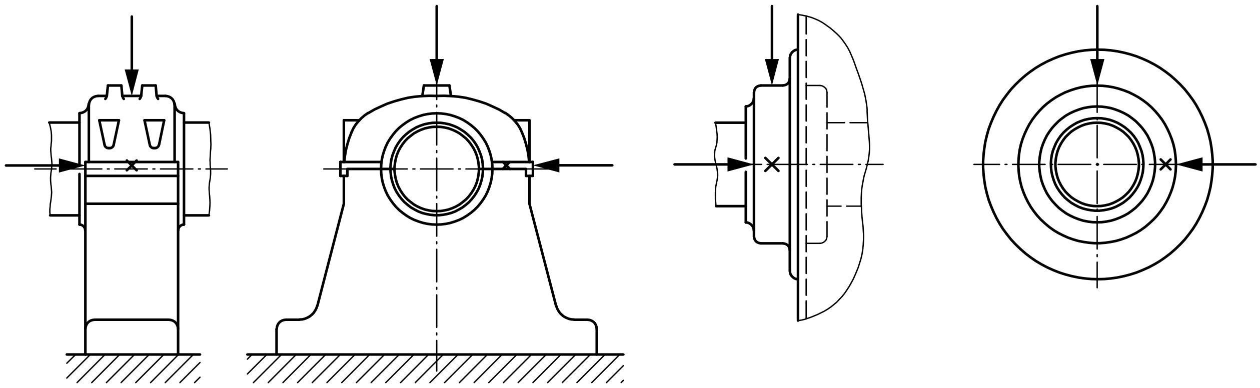
Vibration of mounted components (cooler, consoles, pipes, covers, etc.) is to be considered as local vibration and is not covered explicitly by this part of ISO 20283.

NOTE In certain circumstances, consideration can be given to coupling between torsion and lateral motions in gearboxes.

4.5.5.7 Shaft bearings

Vibration measurements on shaft bearings are always considered to be of interest because lateral vibrations of shafts are difficult to measure and vibration problems, i.e. shafts or parts of a shaft line running in resonance condition, become rather obvious by high vibration amplitudes, velocities or accelerations at the bearing points.

For application of adequate measuring techniques for bearings, reference to ISO 10816-1 is recommended. For measurement points, see Figure 4.



a) Measurent points on pedestal bearings **b) Measurent points on housing-type bearings**

Figure 4 — Measurent points on bearings

Separate standing pedestal bearings are typical for both two-stroke as well as four-stroke engine plants. Since the bearings are passive in respect of generating vibration, the measuring concentrates on registering vibration amplitudes, velocities or accelerations introduced via the shaft (bending vibration) or the foundation (typically propeller- or engine-generated vibration). Engine- or propeller-excited vibration may, however, also be introduced by axial or radial movements of the shafts. Therefore, for analysis purposes, it is essential to distinguish the main source and the path of the vibration, as appropriate, if mathematical models predict resonances close to the main excitation frequencies. Measuring on at least two levels (e.g. at the housing and at the foundation) of such bearings and modal analysis techniques is recommended for proper evaluation.

ISO 10816-1 also refers to “housing type” bearings, which are typically integrated in gearboxes for geared four-stroke engine plants.

NOTE 1 Roller bearings can also be applied as intermediate shaft bearings. Roller bearings are sensitive to vibration (mainly introduced by unbalances), misalignment, and cardan shaft forces. The design of such bearings needs to be adequate for the vibration level of the application. Bearing manufacturers provide guidance for application of special-type bearings for heavy vibration conditions.

NOTE 2 Roller bearings in combination with light shafts (such as carbon-reinforced shafts) are sensitive to vibration, especially when very lightly loaded. It can be advantageous for such cases to produce a due pre-tension (by deliberate misalignment) or to apply specially designed bearings.

4.5.5.8 Integrated propulsion units

Integrated propulsion units, such as mechanical and electrical azimuth drives (also called pod or Z drives), Voith–Schneider units and pump-jets mainly consist of the typical elements of transmission as mentioned in the preceding.

In general, for electrical azimuth drives, similar principles apply as for electric propulsion motors. For mechanical azimuth drives, the principles as laid out for gears, bearings, and shafts are applicable.

For pod propellers and pump-jets, the following general procedure is recommended:

a) the measuring positions for vibration tests should be located on:

  — the bearing housing (power input) tri-axial,

  — shaft bearing tri-axial, see 4.5.5.7,

  — well (hull);

b) for the evaluation, the following considerations have proven to be useful:

  — conversion of acceleration into velocity quantities individually for each measuring position and measuring direction,

  — narrowband analysis up to 1 kHz, Δf approximately 1 Hz, depending on the evaluation criteria,

  — comparison of each result to the evaluation criteria, see Annex B,

  — all measured data and information should be available for post-processing.

NOTE 1 For evaluation of measurement results of pod propellers (especially azimuth drives) and pump-jets, see Annex B.

Direct-driven propellers are not subject to the procedures and evaluation in the preceding.

For very special units, like water jets, Voith–Schneider propellers and transverse thrusters, the guidance values of the manufacturers are applicable. Water jets especially require advanced measuring techniques to be applied in order to filter out and monitor the significant effects. This is due to the high overall vibration level, caused by the water flow, which, as a rule, is much higher than the vibration caused by unbalances or other mechanical effects, indicating high loads of the mechanical components involved.

NOTE 2 For measurements on Voith–Schneider propeller units, see Annex C.

For transverse thrusters, the following procedure is recommended. The measurement points should be located at:

— the flange connection of the gear tunnel, tri-axial;

— the connection of the tunnel to the vertical frame structure of the vessel's hull (for information only);

— the upper part of the electric motor, tri-axial (in case of directly flanged electro motors).

The measurement shall be performed over the entire operational speed range. In case of constant speed thrusters (with controllable pitch propellers), a measurement at nominal speed and in the range covering 80 % to 100 % of output is sufficient.

5 Evaluation criteria

Acceptance criteria shall be agreed upon between the contractually interested parties. For torsional vibration especially, it can be mandatory to fulfil existing rules of the contracted classification society and common design and internationally accepted criteria for marine components, such as gears, shafts, and connections. Design criteria or limits given by the manufacturer of the relevant components are to be fulfilled in any case.

If no other guidelines are available, make reference to the indications given in 4.5 for the different components. As far as available, the specific assessment criteria of component manufacturers take precedence.

6 Test report

A report on the vibration measurements of the propulsion system shall be prepared and shall contain at least the following information:

a) description of the aim of the measurements;

b) description of measuring equipment used, including means used for system test (if any);

c) calibration data to be included if done on site (e.g. electrical calibration of strain gauges);

d) description of measurement points (preferably as sketch): location and orientation of transducers;

e) measurement programme (test runs performed) including trial conditions and operating conditions or configurations for each test run (see 4.2);

f) measured data in suitable form of tables and diagrams: these may include time history data (waveforms), spectra, diagrams versus shaft speed or load (plotted against applicable limits if available), and tables of identified natural frequencies;

g) comments, evaluation (as far as applicable) and conclusions;

h) date and location of tests and name and address of performing organization;

i) particulars of the ship under test in accordance with Table 1.

Table 1 — Particulars of the ship under test

Ship name:	**IMO No.:**
Builder:	**Yard No.:**
Hull data:	
Type (tanker, containership, RO-RO, bulk cargo):	
Class:	
Length between perpendiculars, L_{pp}, m:	
Draft, T (full load), m:	
Propeller(s):	
Number:	
Type (fixed pitch, controllable pitch):	
Number of blades:	
Diameter, D_p, m:	
Rated rotational speed, r/min:	
Engine(s):	
Manufacturer:	
Type:	
Output, maximum continuous rating (MCR), kW:	
Rated (MCR) rotational speed, r/min:	
Number of cylinders:	
Two- or four-stroke engine:	

Annex A
(informative)

Manoeuvring, transient measurements

In addition or in lieu of the tests specified in 4.3 to measure peak values, under certain special conditions, the contractually interested parties may agree to such additions as:

a) hard turns to port and starboard at a contracted speed of the vessel;

b) bollard test (especially applicable for tugs, escort vessels, fishing vessels);

c) astern running;

d) trail shaft test for multi-screw ships;

e) clutch-in procedures;

f) start or stop of plant;

g) switch on or off of a large electrical consumer (e.g. bow thrusters), while shaft generator is excited.

The measurements and assessments as described in this annex fulfil special purposes; consequently, the measuring and data processing equipment shall be selected in a way to fulfil the specific aim.

Annex B
(informative)

Evaluation of vibration at mechanical azimuth drives (e.g. Schottel rudder propellers) and shaft lines by measurements on non-rotating parts

The evaluation criteria given in Table B.1 apply to propulsion units in the power range 100 kW to 4 MW. For the determination of the r.m.s. vibration magnitude, a frequency range 5 Hz to 1 000 Hz should be considered.

The measured vibration velocity value is separated into three zones:

Zone A: Low vibration level

Continuous operation without any restrictions.

Zone B: Medium vibration level, still acceptable working zone

Alignment, foundation and bearings as well as possible damages or errors of the unit should be checked.

Zone C: High vibration level, not allowable working zone

Alignment, foundation, and bearings, as well as possible damages or errors of the unit, need to be checked and the vibration level needs to be reduced by qualified service work.

Table B.1 — Evaluation zones

Zone	A	B	C
r.m.s. vibration velocity, mm/s	≤4,5	≤11,2	>11,2

Annex C
(informative)

Evaluation of the vibration of a Voith–Schneider propeller by measurements on non-rotating parts

C.1 Measurements

C.1.1 Recommended measurement conditions

For correct evaluation of propeller vibration, the vessel should be run with nominal speed at 100 % of maximum continuous rating with a constant heading.

C.1.2 Measuring positions

The measuring positions for vibration tests should be located on the following positions, see Figure C.1:

— M1: measurement of the vibration on top of the input gear;

— M2: measurement of the vibration on the edge of the first housing arm in a stiff area;

— M3: measurement of the vibration on the edge of the second housing arm in a stiff area.

All measurement points should be measured uniaxial in vertical direction.

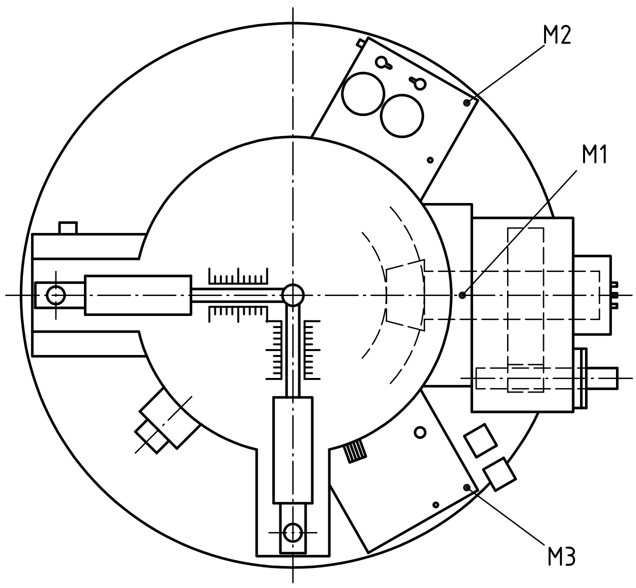


Figure C.1 — Measuring positions

C.1.3 Measurement settings

All measurements should be performed as narrow-band analysis with the following settings:

— frequency range: 1 Hz to 1 000 Hz;

— measurement quantity: r.m.s. vibration velocity, millimetres per second (mm/s).

C.2 Evaluation

All measured data or information should be available for post-processing, preferably in electronic formats. The narrow-band analysis should be compared to the evaluation criteria. See also ISO 10816-1.

The measured vibration value is separated into three zones:

Zone A: Low r.m.s. vibration value (≤4,5 mm/s)

Continuous operation without any restrictions.

Zone B: Medium r.m.s. vibration value (>4,5 mm/s and ≤7,1 mm/s)

Still acceptable working conditions, but with the help of a frequency analysis, the most important peaks with their belonging frequencies should be identified.

Zone C: High r.m.s. vibration value (>7,1 mm/s)

Unacceptable working condition. The vibration has to be checked in more detail and actions have to be taken to reduce the vibration level. This has to be done by qualified service work.

NOTE In general, resonance effects of the vessel are excluded.

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