INTERNATIONAL STANDARD

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Mechanical vibration — Measurement of vibration on ships —

Part 2:
Measurement of structural vibration

Vibrations mécaniques — Mesurage des vibrations à bord des navires —

Partie 2: Mesurage des vibrations structurelles

Reference number
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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 20283-2 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

This part of ISO 20283 cancels and replaces ISO 4867:1984 and ISO 4868:1984, of which it constitutes a technical revision.

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*

The following parts are under preparation:

— *Part 1: General guidelines*

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

Introduction

Vibration in a ship is generated by machinery, propeller and sea. The vibration responses of the ship structure at different locations are dependent on the dynamic forces and natural frequencies. The dynamic forces vary with the engine load, and the speed and draught of the ship. The natural frequencies vary with the loading condition and draught of the ship.

Global structural vibration in a ship is highly dependent on these parameters. This part of ISO 20283 gives guidance how to obtain an overall picture of the vibration behaviour of the ship by setting up guidelines for measurement of natural frequencies and vibration responses at selected positions under a given loading condition of the ship.

Such data are necessary to describe uniformly the vibration characteristics of ship hulls and the relevant excitation originating from the propulsion plant. This will provide a basis for improved vibration engineering, *i.e.*, systematic comparison against theoretical predictions, other ships and vibration reference levels.

Inclusion of this part of ISO 20283 in the building specification or the contract between purchaser and builder does not necessarily require the measurements and evaluations as described in this part of ISO 20283.

Mechanical vibration — Measurement of vibration on ships —

Part 2: Measurement of structural vibration

1 Scope

This part of ISO 20283 gives guidelines, and specifies requirements and procedures for the measurement, diagnostic evaluation and reporting of structural vibration of ships, excited by the propulsion plant. Structural vibration can be of global or of local nature. Here, primarily global vibration is dealt with.

Local vibration of deck structures from a habitability point of view is dealt with in ISO 6954. Occurrence of local vibration leading to fatigue damage is rare and strongly related to the individual configuration. Therefore, no general guideline for the measurement of such type of vibration is provided within the scope of ISO 20283 (all parts). For reference, some basic information regarding the design of structures with respect to local structural vibration is provided in Annex D.

This part of ISO 20283 does not consider transient ship vibration phenomena, *e.g.*, as excited by slamming.

Even though torsional shaft or crankshaft vibration can in some cases cause relevant structural vibration, they are not considered here. In this connection, reference can be made to the relevant classification rules and ISO 20283-4.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2041: *Mechanical vibration, shock and condition monitoring — Vocabulary* [1)]

3 Terms and definitions

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

3.1
global structural vibration
vibration deflection shapes involving major structural parts of the ship

NOTE Major parts of a ship include: hull girder, superstructure, and aft body.

1) To be published. (Revision of ISO 2041:1990)

3.2
local structural vibration
vibration deflection shapes which are limited to one structural part of the ship

NOTE Local parts of a ship include: parts of the superstructure, mast, tank bulkheads, web frame, stiffener, and plate.

3.3
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

3.4
hull girder
primary hull structure contributing to flexural rigidity of the hull, the static and dynamic behaviour of which can be described by a free-free non-uniform beam approximation

NOTE Primary hull structure includes: shell plating, continuous longitudinal strength members and stiffeners, and continuous strength decks.

3.5
operational vibration deflection shape
vibration pattern reflecting the dynamic response of the hull structure to a vibration excitation (forced response)

4 Measurement conditions and manoeuvres

A set of measurements is recommended to be performed on the first ship of a series (if any) to show that it does not suffer from vibration deficiencies with respect to global vibration. These measurements are conducted for informational purposes and include comparison with results of theoretical prediction, and not with the aim to confirm compliance with any vibration level limit values. Nevertheless, measurement evaluation should include comparison with results of theoretical predictions and measurement results obtained for other ships.

The water depth shall be more than 5 times the ship draught. If the ship is intended for service in shallow waters, the trial depth shall be chosen accordingly.

The sea state shall be below 3. If greater than 3, the sea state shall be noted in the measurement report and the report should also contain a section with signal analysis applied to high-pass filtered measurement data ($>$ 2 Hz).

The ship shall be loaded so that, as a minimum, the propeller is fully immersed. This loading condition (test condition) during sea trial of the ship should preferably be a normal operating condition (ballast or loaded condition). It should be considered that for ships with larger variation in relevant displacements, global vibration characteristics may change significantly. Tendencies can be concluded from theoretical investigations, if available. If measurements during ship service conditions need to be carried out for further diagnosis, the procedures as provided in this guideline should be applied in analogy. In such cases, measurement transducers should be placed also at the bow into transverse and vertical directions to better capture the change of the natural frequencies of the global hull vibration modes with varying loading condition.

For the determination of the main operational vibration deflection shapes and the associated natural vibration mode shapes and frequencies, measurements shall be conducted in free route runs in the speed range corresponding to approximately 30 % to 100 % of maximum continuous rated power. The following sequence is recommended.

a) Fixed pitch propellers: measure at discrete constant rotational speed steps with increases of approximately 2 % of maximum continuous rated propeller shaft rotational speed. Alternatively, if a harmonic order tracking technique is applied for data acquisition and analysis, rotational propeller shaft speed (propulsion shaft speed) may be increased slowly and continuously over a period not less than 45 min. An even lower rate of change of rotational speed or smaller steps should be used in or near resonance conditions, allowing for approximately continuous quasi-stationary conditions.

b) Controllable pitch propellers: the ship's standard combinatory curve for rotational speed and pitch increments leading to at least 20 measurement sets over the ship's operational speed range. If resonances cannot be identified by this procedure, the pitch shall be kept constant at approximately 80 % and the rotational speed rate changed in such a way as to cover the frequency range of interest adequately.

During each step, data should be recorded for at least 60 s.

If quasi-continuous operating conditions have not been ensured during speed-up trials, the following rotational speed and pitch settings shall be measured at separate constant rotational speed over a duration of 3 min:

— nominal rotational speed and pitch setting;

— rotational speed and pitch setting for which maximum response on navigation bridge deck level is obtained and which is excited by the dominant propeller excitation order;

— rotational speed and pitch setting for which maximum response on navigation bridge deck level is obtained and which is excited by the dominant main engine excitation order.

In multiple-shaft ships, all shafts should be run at, or as close as possible to, the same rotational speed to determine total vibration levels.

5 Measurement positions

The focus is on the determination of the global operational deflection shapes, the indication of important natural vibration modes and on the identification of the dominant vibration excitation mechanisms. Consequently, measurement positions shall reflect the ship's deflection shape and the energy and frequency content of the main vibration excitation sources, as normally represented by propeller and main engine.

For the determination of suitable measurement positions, reference to the theoretical global vibration analysis, if available, should be made. If no analysis is available, guidance for the selection of the measurement positions can be obtained from Annex A.

For the evaluation of the magnitude and characteristic of propeller excitation, optionally, pressure pulse measurements in the shell area above the propeller may be made. The measured data may be used for validation of theoretical predictions and cavitation tank tests. Moreover, disadvantageous propeller cavitation phenomena, *i.e.*, broad-band excitations or dominance of higher blade harmonics, can be identified. During the measurements, care shall be taken that the shell area above the propeller is fully immersed. See Annex B for guidance on the selection of the measurement positions.

The measurement programme and positions should be agreed on between builder and purchaser before the performance of sea trials.

6 Signal acquisition, processing and storage

Transducers shall be calibrated in the laboratory. The total vibration measuring system including the cabling shall be checked in the field before and after performing the measurements.

In order to perform the recommended diagnostic measurements in reasonable time and to allow for phase considerations and modal analysis, use of multi-channel equipment is recommended. If this is not possible, at least two-channel equipment shall be used with one channel reserved as reference channel.

The vibration transducers and the signal processing equipment shall be capable of measurement from 1 Hz to 80 Hz with a magnitude accuracy for the entire system of at least ± 5 % and a frequency resolution of at least 0,125 Hz.

For the calculation of the frequency spectra from the time series, preferably a flat top (low level uncertainty) or Hanning (good frequency resolution) window should be used. Alternatively, an order tracking method can be applied.

Since mean and not extreme values are of interest for Fourier transform, the stable mean averaging mode shall be used (*i.e.*, not peak-hold).

In case further analysis is required after the trials, measurement data shall be stored on an electronically reproducible medium.

7 Test report

General information on ship and propulsion plant characteristics, ambient and operating conditions during the measurements shall be provided. Guidance can be obtained from the measurement report form given in ISO 6954.

Additionally, the following information shall be provided for proper comparison with theoretical prediction results:

a) a reference to this part of ISO 20283;

b) fore and aft draft during tests;

c) estimated height of stern wave during tests or immersion state of the shell structure above the propeller, respectively;

d) filling state of aft peak tank, if any;

e) arrangement and type of transverse main engine stays, if any;

f) arrangement and type of axial vibration damper, if any;

g) arrangement and type of torsional vibration damper, if any;

h) arrangement and type of vibration balancer, if any.

Preferred units for the data presentation are:

— acceleration: millimetres per second squared (mm/s^2);

— velocity: millimetres per second (mm/s);

— displacement: millimetres (mm);

— pressure: kilopascals (kPa).

The measured vibration levels shall preferably be documented in terms of the peak value of the vibration velocity. If any frequency weighting is applied, this shall be clearly indicated.

It is recommended also to list the vibration levels in terms of the overall frequency-weighted root mean square (r.m.s.) value as defined in ISO 6954 for a tentative assessment of the vibration levels from a habitability point of view.

The measurement results shall be documented in such a way as to reflect the variation of vibration characteristics with changing rotational speed or pitch settings, respectively. It shall be possible to conclude on the level and frequency content of the vibration response at each relevant measurement step.

Optionally, typical time series and graphs of vibration response versus rotational speed or pitch setting should be included for all relevant excitation orders.

Also, schematic plots or bar model animations of the relevant natural and operational mode shapes provide additional useful information, *e.g.*, for comparison with theoretical predictions.

Generally, presentation in graphical form is preferred rather than tabular listings. Two examples of result presentation for two measurement positions are presented in Annex C.

Any remarkable observations and phenomena having occurred during the measurements (*e.g.*, beating, severe slamming induced vibration) shall be reported.

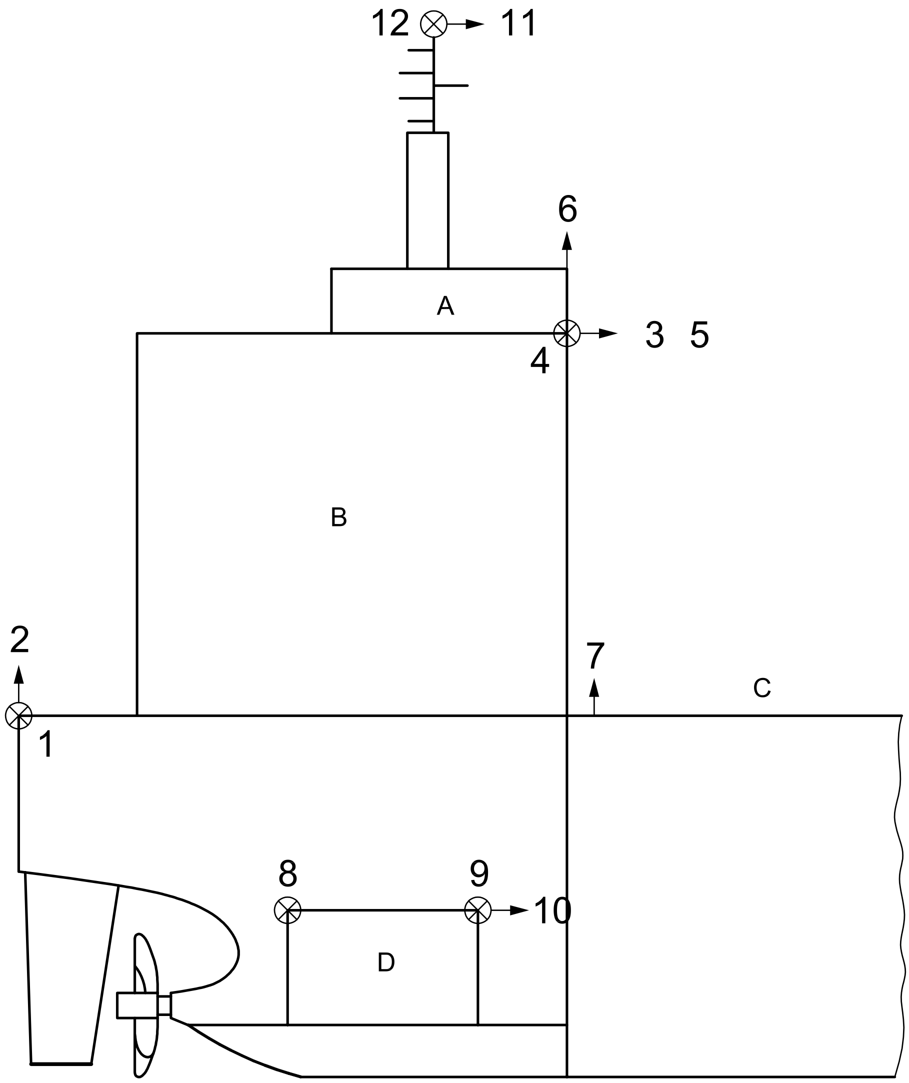
Furthermore, a brief discussion of the results and a comparison with calculated figures, if available, and the main conclusions from the measurement should be included.

Electronic format is preferred, but paper format is acceptable.

Annex A
(informative)

Typical extent of measurement positions for global ship vibration

For ships characterized by a clear separation of hull and superstructure and equipped with slow or medium-speed engines, *e.g.*, tankers, bulk carriers, multi-purpose and container ships, at least the measurement positions listed in Table A.1 and shown in Figure A.1 should be considered.



Key

A navigation bridge deck

B superstructure

C upper deck, main deck

D main engine

NOTE For numbers, see Table A.1.

Figure A.1 — Illustration of global vibration measurement positions for typical merchant ships

Table A.1 — Global vibration measurement positions for typical merchant ships

No.	Location	Direction
1	Stern, port	Transverse
2	Stern, port	Vertical
3	Navigation bridge deck forward, port	Longitudinal
4	Navigation bridge deck forward, port	Transverse
5	Navigation bridge deck forward, starboard	Longitudinal
6	Navigation bridge deck forward, port	Vertical
7	Superstructure fore, foundation, centre line	Vertical
8	Main engine top, aft cylinder frame	Transverse
9	Main engine top, fore cylinder frame	Transverse
10	Main engine top, fore cylinder frame	Longitudinal
11[a]	Main mast top	Longitudinal
12[a]	Main mast top	Transverse

[a] It is recommended also to check the vibration characteristics of the main mast, measurement of the transverse and longitudinal vibration level at the main mast top.

Annex B
(informative)

Procedure for optional propeller pressure pulse measurements

B.1 Pressure transducers

The pressure transducers, signal conditioning and recording system should have a frequency response range which will measure the impulsive pressures arising from cavitation. An upper frequency response of about 5 kHz should be adequate for most purposes.

Corrosion resistant pressure transducers should be used. Ideally the sensitive membrane of the transducer should be flush with the outer hull surface in order to avoid unwanted pressure harmonics. The design of available transducers and fitting sometimes make this difficult to achieve in practice.

B.2 Pressure components

The hull surface pressure comprises two components. The first is the direct radiated pressure from the propulsor and the second is a self-induced pressure resulting from the vibration of the transducer mounted on the hull.

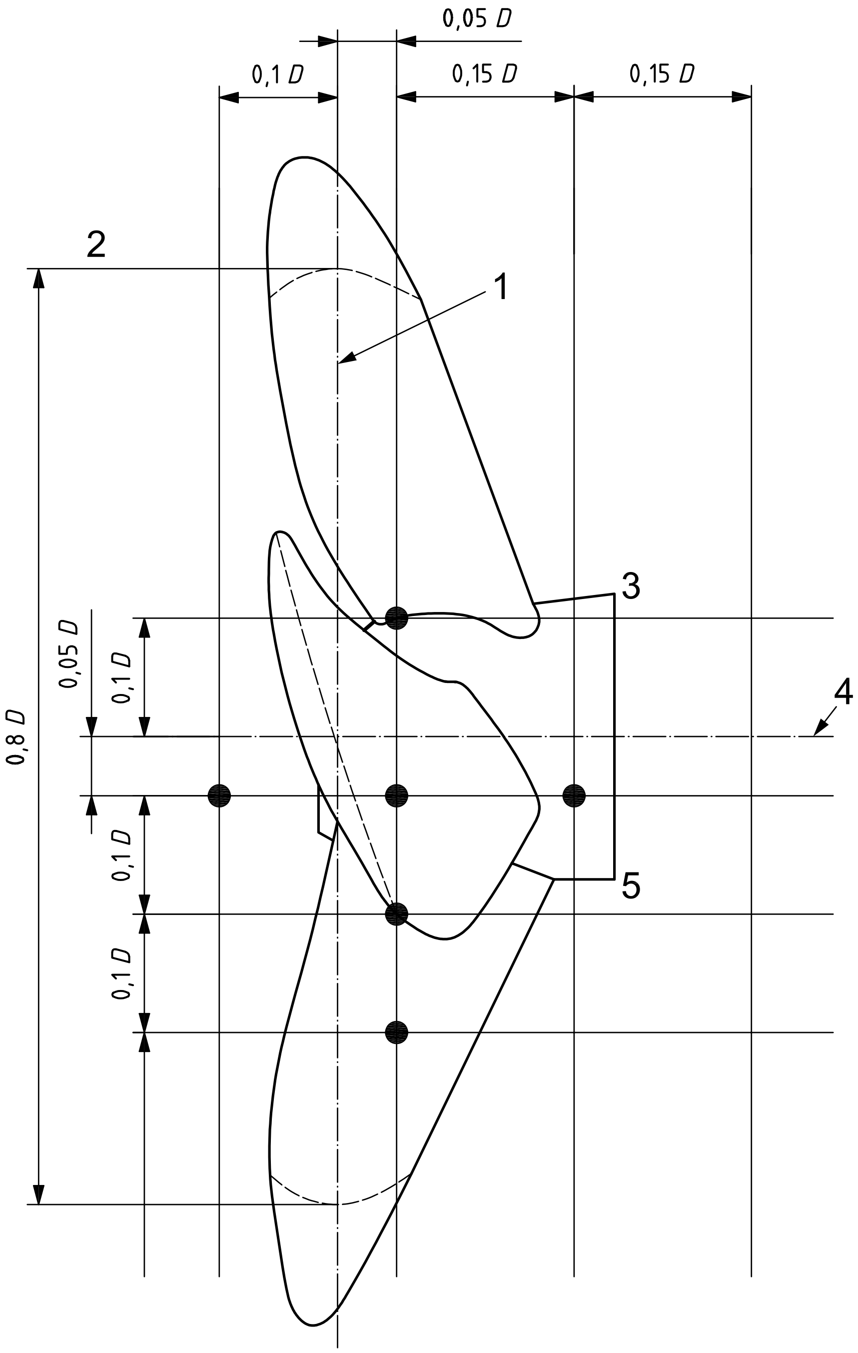
To separate these two components, it is necessary to measure the vibration at the pressure transducer locations. These data, via suitable transformation methods, can be used to estimate the self-induced pressure components in terms of amplitude and phase at the transducer location.

B.3 Measurement locations

The number of pressure transducers should, ideally, be between five and seven. For a right-handed propeller of diameter, D, four pressure transducers should be placed at 0,05D to starboard of the shaft centre line (see Figure B.1). The longitudinal positions should be in the measurement reference plane at intervals of 0,15D, starting at 0,1D aft of the propeller tip plane. At the plane 0,05D ahead of the propeller tips additional transducers may ideally be placed at 0,1D to port and 0,15D and 0,25D to starboard. The mirror image of this pattern should be applied for a left-handed propeller.

For ships with significant areas of shell plating aft of the propeller plane pressure transducers may also be required to be located at distances up to 2D aft of the propeller plane in line with the principal tip vortex activity in the wake peak.

A phase marker or angular position indicator should be fitted to the inboard shafting. It is convenient if this coincides with a particular blade at a known angular position of the propeller.



Key

1 measurement reference plane

2 mid-chord

3 port

4 shaft centre line

5 starboard

NOTE The figure is drawn for right-handed propeller seen from above. Positions for left-handed propeller are mirrored on the shaft centre line.

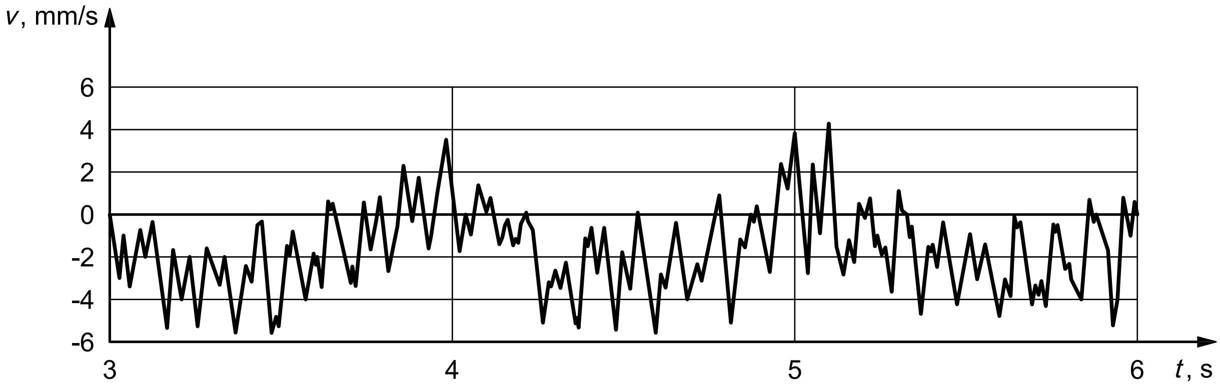
Figure B.1 — Measurement locations on a propeller with diameter, *D*

Annex C
(informative)

Examples for a result presentation of global vibration measurement

C.1 Example 1

Measurement position: navigation bridge deck, longitudinal

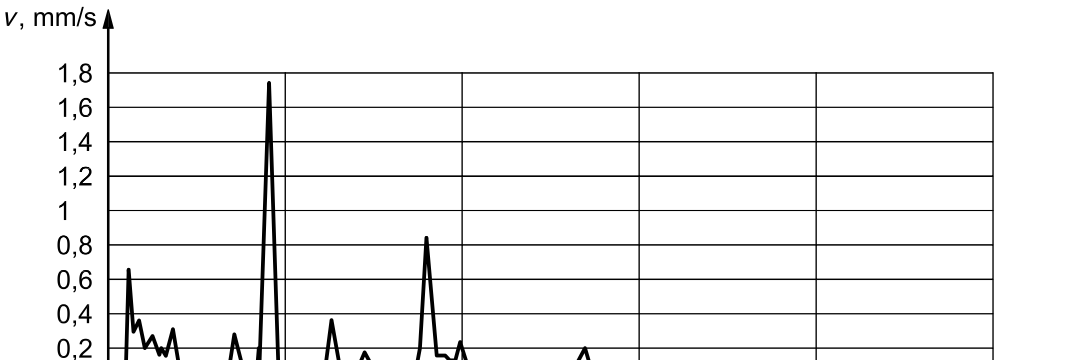


Key

t time

v velocity

Figure C.1 — Time history, constant rotational speed, n = 108 r/min

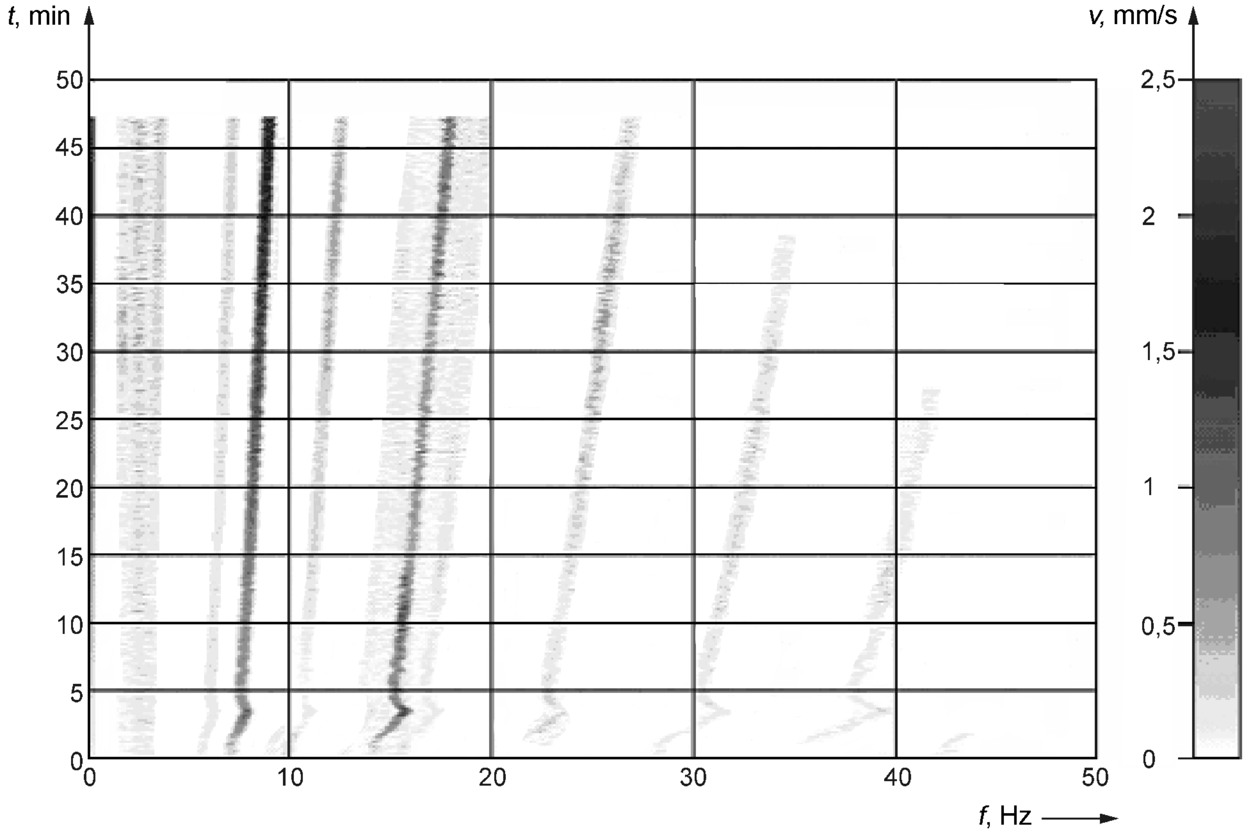


Key

f frequency

v velocity

Figure C.2 — Fourier spectrum, constant rotational speed, n = 108 r/min



Key

f frequency

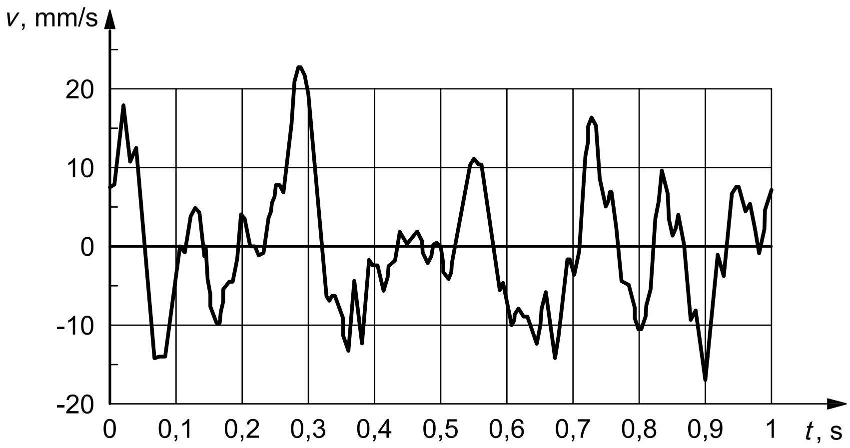
t time

v velocity

Figure C.3 — Waterfall diagram, rotational speed, $n = 85$ r/min **to** $n = 108$ r/min

C.2 Example 2

Measurement position: main engine top, transverse

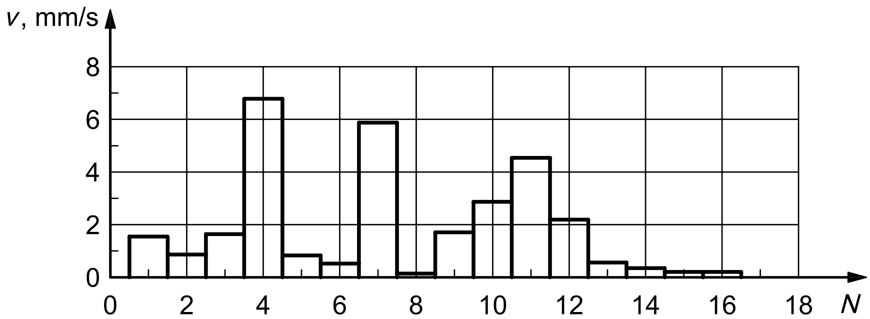


Key

t time

v velocity

Figure C.4 — Time history

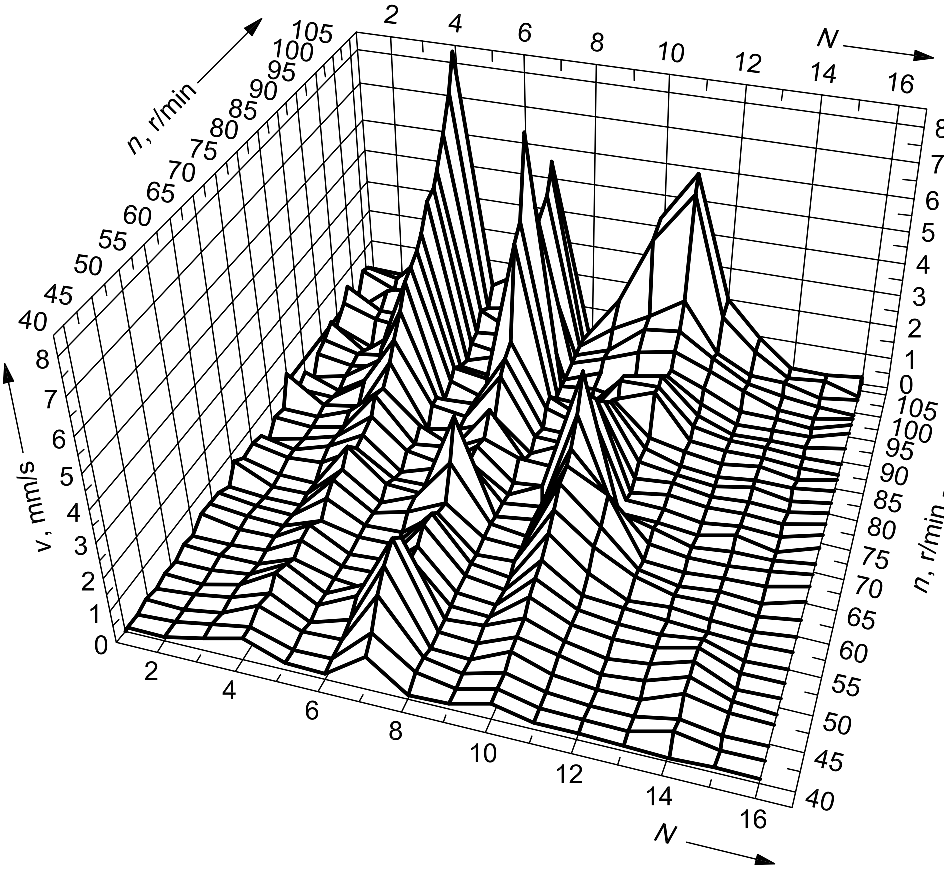


Key

N order

v velocity

Figure C.5 — Order spectrum, constant rotational speed, $n = 103$ r/min



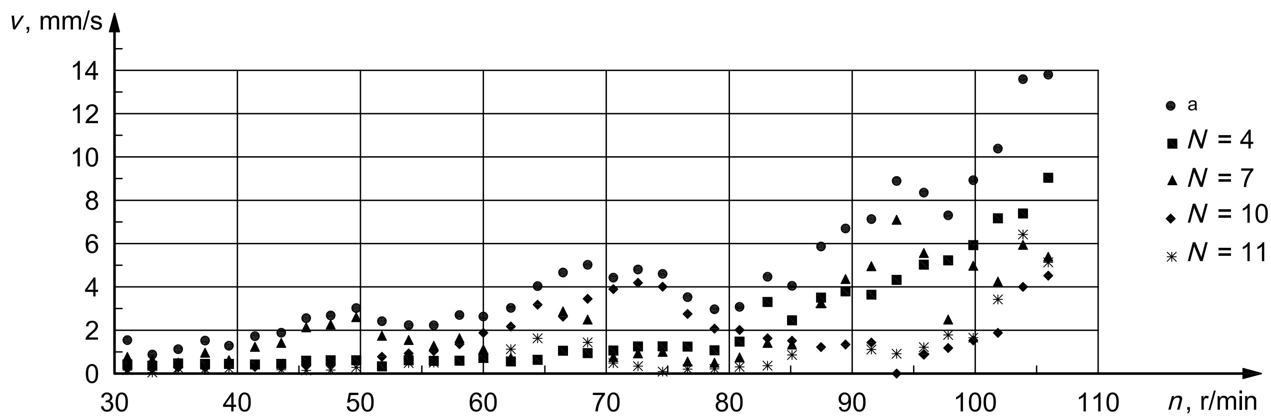
Key

N order

n rotational speed

v velocity

Figure C.6 — Waterfall diagram



Key

N order

n rotational speed

v velocity

[a] overall peak

Figure C.7 — Order plot versus rotational speed

Annex D
(informative)

Local structural vibration

At structural design stage, natural frequencies of local panels and stiffened panels especially in the superstructure, the engine room and the stern-end structure can be estimated by using simplified theoretical formulae or finite element analysis. These local panel scantlings are decided by setting these estimated natural frequencies apart from the exciting frequencies induced by propellers, main engines and so on to adequate extent to avoid resonance. The builder will decide the differences between these estimated natural frequencies and the exciting frequencies considering the results of measured frequencies of local panels and stiffened panels for former ships.

During the performance trial of the ship, the vibration level of local panels in conspicuous areas should be checked visually by taking note of the noise and the overall vibration velocity values at the most representative spots for reference. These observations or measurements should be conducted at or close to the nominal rotational speed of the propulsion plant, and the frequency range 5 Hz to 100 Hz should be considered. To minimize the risk of structural damage, panels with values above 30 mm/s might need further attention. To assess the extent of introduction of structure-borne noise, *e.g.*, at top plates of engine or gear foundations, other assessment criteria need to be used.

Bibliography

[1] ISO 6954, *Mechanical vibration — Guidelines for the measurement, reporting and evaluation of vibration with regard to habitability on passenger and merchant ships*

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