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ISO
10816-6

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

Part 6:

Reciprocating machines with power ratings
above 100 kW

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

Partie 6: Machines alternatives de puissance nominale supérieure à 100 kW



Reference number
ISO 10816-6:1995(E)

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 electro-technical standardization.

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.

International Standard ISO 10816-6 was prepared jointly by Technical Committees ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*, and ISO/TC 70, *Internal combustion engines*, Subcommittee SC 2, *Performance and tests*.

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

- *Part 1: General guidelines*
- *Part 2: Large land-based steam turbine generator sets in excess of 50 MW*
- *Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*
- *Part 4: Gas turbine driven sets excluding aircraft derivatives*
- *Part 5: Machine sets in hydraulic power generating and pumping plants*
- *Part 6: Reciprocating machines with power ratings above 100 kW*

Annex A forms an integral part of this part of ISO 10816. Annexes B to D are for information only.

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Introduction

ISO 10816-1 gives general guidelines for the evaluation of machine vibration by measurements on non-rotating parts. This part of ISO 10816 is a new document which establishes procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating machines. In general, this part of ISO 10816 refers to vibration of the main structure of the machine, and the guide values given for these vibrations are defined primarily to classify the vibration of the machine and to avoid problems with auxiliary equipment mounted on this structure. Recommendations for measurements and evaluation criteria are provided in this part of ISO 10816.

Typical features of reciprocating machines are the oscillating masses, the cyclically varying output (input) torques and the pulsating forces in the associated pipework. All these features cause considerable alternating forces on the main supports and vibration amplitudes of the main frame. The vibration amplitudes are generally higher than for rotating machinery but, since they are largely determined by the design features of the machine, they tend to remain more constant over the life of the machinery than for rotating machinery.

In the case of reciprocating machines, the vibration measured on the main structure of the machine and quantified according to this part of ISO 10816 may only give a rough idea of the stresses and vibratory states of the components within the machine itself. For example, torsional vibration of rotating parts cannot generally be determined by measurements on the structural parts of the machine. The damage, which can occur when exceeding the guide values based on experience with similar machines, is sustained predominantly by machine-mounted components (e.g. turbochargers, heat-exchangers, governors, filters, pumps), connecting elements of the machine with its peripheral parts (e.g. pipelines) or monitoring instruments (e.g. pressure gauges, thermometers). The question as from which vibration values damage is to be expected largely depends on the design of these components and their fastenings.

In some cases, special measurements on certain machine components will be required to ascertain that the vibration values are permissible. It also happens that even if measured values are within permissible guide values, problems may occur owing to the great variety of components which can be attached. Such problems can be, and have to be, rectified by specific "local measures" (e.g. by elimination of resonances). Experience has shown, however, that it is possible in the majority of cases to state measurable quantities characterizing the vibratory state and to give guide values for these. This shows that the measurable variables and the guide values permit a reliable evaluation in most cases. For the quantity described, which characterizes the vibration values of reciprocating piston machines in a simple manner, the term "vibration severity" will be used.

The vibration values of reciprocating piston machines are not only affected by the properties of the machine itself but also to a large degree by the foundation. Since a reciprocating machine can act as a vibration generator, vibration isolation between the machine and its foundation may be necessary. This, as well as the vibration response of the foundation, can have considerable effect on the vibration of the machine itself. These vibration conditions are also dependent on the transmissibility of the environment surrounding the machine and are therefore not entirely determined by the vibration values of the machine itself. This part of ISO 10816 can therefore only take an advisory role in relation to the effects of the machine on the environment.

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

Part 6:

Reciprocating machines with power ratings above 100 kW

1 Scope

This part of ISO 10816 specifies the general conditions and procedures for the measurement and evaluation of vibration, using measurements made on the non-rotating and non-reciprocating parts of complete machines. Shaft vibration, including torsional vibration, is beyond the scope of this part of ISO 10816.

It generally applies to reciprocating piston machines mounted either rigidly or resiliently with power ratings of above 100 kW. Typical examples of application are: marine propulsion engines, marine auxiliary engines, engines operating in diesel generator sets, gas compressors and engines for diesel locomotives.

The general evaluation criteria which are presented relate to both operational monitoring and acceptance testing. They are also used to ensure that the machine vibration does not adversely affect the equipment directly mounted on the machine.

Consideration should also be given to the machinery driven by or driving the reciprocating machine. These should be evaluated in accordance with relevant standards and classification for the intended duty.

It is recognized that the evaluation criteria may only have limited application when considering the effects of internal machine components; for example, problems associated with valves, loose pistons, piston rings, etc. are unlikely to be reflected in the measurements. Identification of such problems requires investigative

techniques which are outside the scope of this part of ISO 10816. Noise is also outside the scope of this part of ISO 10816.

This part of ISO 10816 does not apply to machines installed in road vehicles (e.g. trucks, passenger cars, self-propelling construction machinery and tractors).

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this part of ISO 10816. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this part of ISO 10816 are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2041:1990, *Vibration and shock — Vocabulary*.

3 Definitions

For the purposes of this part of ISO 10816, the definitions given in ISO 2041 and the following definition apply.

3.1 vibration severity: A generic term that designates a value, or set of values, such as a maximum value, average or r.m.s. value, or other parameter that is

descriptive of the vibration. It may refer to instantaneous values or average values.

NOTE 1 ISO 2041 includes two notes in the above definition. These notes are not applicable to this part of ISO 10816.

4 Measurements

4.1 Measuring instrument and measured quantities

Criteria for classifying vibration severity for reciprocating machines are specified in clause 5. The classifications are based on measurement of overall values of vibration displacement, velocity and acceleration over a frequency range of 2 Hz to 1 000 Hz.

It is recognized that the main excitation frequencies for reciprocating machines are generally found in the range 2 Hz to 300 Hz. However, when considering the complete machine including auxiliary equipment that is a functional part of the machine, a range of at least 2 Hz to 1 000 Hz is required to characterize the vibration. For special purposes, a different range may be agreed between the manufacturer and customer.

Since the overall vibration signal usually contains many frequency components, there is no simple mathematical relationship between the r.m.s. and peak, or peak-to-peak overall vibration measurements. Therefore the preferred measuring system should provide the overall r.m.s. values of displacement, velocity and acceleration with an accuracy of $\pm 10\%$ over the range 10 Hz to 1 000 Hz and an accuracy of ${}_{-20}^{+10}\%$ over the range 2 Hz to 10 Hz. These values may be obtained from a single sensor whose signal is processed to derive the quantities not directly measured (e.g. an accelerometer whose output is integrated once for velocity and twice for displacement). Care should be taken to ensure that any processing does not adversely affect the required accuracy of the measuring system.

Both the frequency response and measured vibration amplitudes are affected by the method of attachment of the transducer(s). It is especially important to maintain a good attachment between the transducer and the machine when the vibration values are high. For example, ISO 5348 gives guidance on the mounting of accelerometers.

4.2 Points and direction of measurement

To ensure that the evaluation of the vibration measurements is as uniform as possible and, further, that the best possible comparison between different machines is achieved, preferred measurement positions are specified in figures 1 to 3. Generally, measurements should be taken at these points in the three machine-related main directions indicated.

The machines presented in figures 1 to 3 are examples only. For different versions (e.g. radial machines), similar measurement points apply.

Provided it is known from experience with similar machines at which points the maximum vibration severity is to be expected, it is not necessary to consider all the points specified in the figures. Accessible load-carrying bearing positions should be included. However, for acceptance testing, if fewer measurement points are used, this should be agreed between the manufacturer and customer.

If several measurement points are taken into account for more careful investigation or for comparative purposes, it is recommended that those of figures 1 to 3 be preferred.

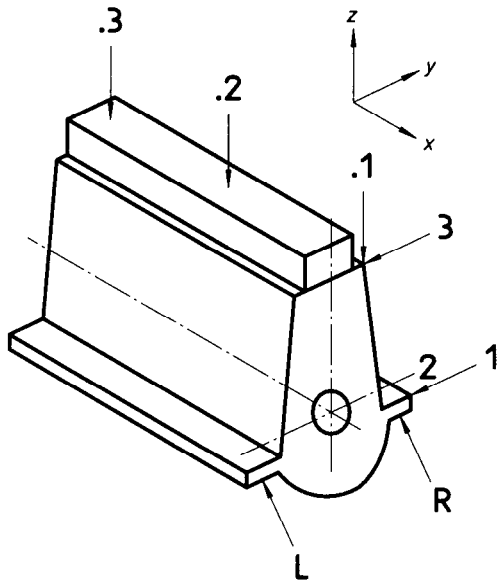
When selecting the exact measurement points, the configuration and installation restrictions of the particular machine involved should be allowed for. All measurement points are to be chosen in such a way that the vibration transducer is properly attached to the main structure of the machine.

Vibration measurements of machine-mounted components may give useful information regarding their failure, however the guide values referred to in this part of ISO 10816 apply to the positions given in figures 1 to 3 on the main structure of the machine.

EXAMPLE

The right-hand top edge of a frame, on the coupling end of a machine, in the *y* (horizontal) direction is designated as:

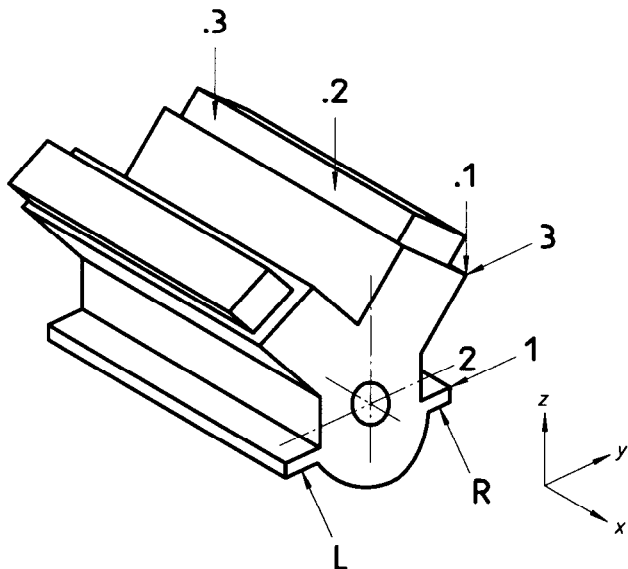
R3.1 y



Key

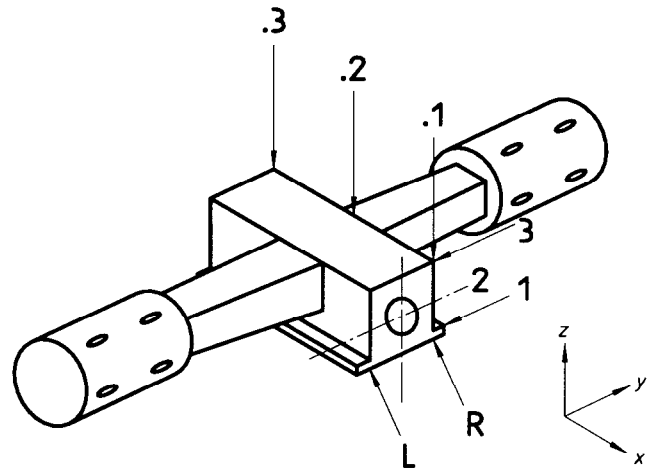
Sides of measurement	L	Left-hand when facing the coupling flange
	R	Right-hand when facing the coupling flange
Levels of measurement	1	Machine end of mounting
	2	Crankshaft level
	3	Top edge of frame
Measurement points related to machine length	.1	Coupling end
	.2	Mid-machine
	.3	Free end of machine

Figure 1 — Example of a vertical in-line machine



NOTE — See figure 1 for key.

Figure 2 — Example of a multicylinder Vee machine



NOTE — See figure 1 for key.

Figure 3 — Example of a horizontal opposed machine

4.3 Operating conditions during measurements

Measurements should be taken when the machine has reached its steady-state operating conditions (e.g. normal operating temperature). The determination of the machine vibration severity shall be based on the maximum vibration occurring over the entire power and speed range approved for normal operation.

4.4 Record of measured results

Records of measured results should include essential data of the machine and of the measuring system used. These data may be entered on forms 1 and 2, given in annex B, which can serve as a measurement record.

5 Vibration criteria

Vibration severity grades are presented numerically in table 1, and graphically in annex C. In order to quantify these it is necessary to measure the overall (broad-band) r.m.s. values (2 Hz to 1 000 Hz) of displacement, velocity and acceleration. Severity grades shall be obtained for each of the highest overall r.m.s. value of the displacement, velocity and acceleration measured on the main structure of the machine. The machine vibration severity grade is the highest of these three grades.

As an example, the vibration values given in table 2 were obtained at position R3.1 on the main structure of a machine. The corresponding vibration severity grades from table 1 are given in square brackets. As a conclusion, the machine vibration severity grade at this position is therefore 28. All other positions should be reviewed similarly to establish the maximum vibration severity grade over the machine.

Table 1 — Vibration severity grades
(2 Hz to 1 000 Hz)

Vibration severity grade	Limiting values of overall vibration measured on the machine structure		
	Displacement µm (r.m.s.)	Velocity mm/s (r.m.s.)	Acceleration m/s ² (r.m.s.)
1,1	≤ 17,8	≤ 1,12	≤ 1,76
1,8	≤ 28,3	≤ 1,78	≤ 2,79
2,8	≤ 44,8	≤ 2,82	≤ 4,42
4,5	≤ 71,0	≤ 4,46	≤ 7,01
7,1	≤ 113	≤ 7,07	≤ 11,1
11	≤ 178	≤ 11,2	≤ 17,6
18	≤ 283	≤ 17,8	≤ 27,9
28	≤ 448	≤ 28,2	≤ 44,2
45	≤ 710	≤ 44,6	≤ 70,1
71	≤ 1125	≤ 70,7	≤ 111
112	≤ 1784	≤ 112	≤ 176
180	> 1784	> 112	> 176

NOTE — The values were derived from constant displacement in the range 2 Hz to 10 Hz, constant velocity from 10 Hz to 250 Hz and constant acceleration from 250 Hz to 1 000 Hz.

The vibration severity value associated with a particular type of machine depends on its size and mass, the characteristics of the mounting system and the operating conditions, etc. It is therefore necessary to take account of the various purposes and circumstances concerned when applying the vibration severity grades. The maximum value measured across the overall length of the machine will then be used for determining the vibration severity. Reciprocating machine classification numbers and guide values are presented in annex A.

Flexible mountings are used extensively to reduce the effect of a machine on its environment. The design and application of these are outside the scope of this part of ISO 10816.

NOTES

- 2 Guidelines for vibration isolators are given in ISO 2017.
- 3 Guidelines for vibration effects on buildings are given in ISO 4866.

Table 2 — Example of vibration values

Position	Measured vibration values		
	Displacement µm (r.m.s.)	Velocity mm/s (r.m.s.)	Acceleration m/s ² (r.m.s.)
R3.1x	100 [grade 7,1]	15 [grade 18]	9 [grade 7,1]
R3.1y	150 [grade 11]	16 [grade 18]	8 [grade 7,1]
R3.1z	250 [grade 18]	22 [grade 28]	10 [grade 7,1]

Annex A

(normative)

Machine vibration classification

Vibration classification numbers and guide values for reciprocating machines are given in table A.1. The guidance values assist in evaluating the vibration severity to which the machine frame and attached ancillaries and equipment may be subjected.

A reciprocating machine could well be classified by more than one class depending upon its type, application, size, configuration, flexible or rigid mounting and speed. For example, many industrial and marine diesel engines may be classified in either classification number 5, 6 or 7.

As and when circumstances permit, recommendations for acceptable guide values of vibration severity for particular types of machine will be prepared. Until such time, classifications may be agreed between the manufacturer and customers, using experience or results of operation.¹⁾

1) Information on vibration values of reciprocating machines collected in accordance with this part of ISO 10816 are welcomed and should be communicated to the national standards body in the country of origin for transmission to the secretariat of ISO/TC 108/SC 2.

Table A.1 — Vibration classification numbers and guide values for reciprocating machines

Vibration severity grade	Maximum values of overall vibration measured on the machine structure			Machine vibration classification number							
	Displacement µm (r.m.s.)	Velocity mm/s (r.m.s.)	Acceleration m/s ² (r.m.s.)	1	2	3	4	5	6	7	
				Evaluation zones							
1,1	17,8	1,12	1,76	A/B	A/B	A/B	A/B	A/B	A/B	A/B	
1,8	28,3	1,78	2,79								
2,8	44,8	2,82	4,42								
4,5	71,0	4,46	7,01								
7,1	113	7,07	11,1	C	D	D	D	D	D	D	
11	178	11,2	17,6	C							
18	283	17,8	27,9	C							
28	448	28,2	44,2	C							
45	710	44,6	70,1	D	D	D	D	D	D	D	
71	1125	70,7	111								C
112	1784	112	176								D
180											D

Key to zones

A: The vibration of newly commissioned machines would normally fall within this zone.

B: Machines with vibration within this zone are normally considered acceptable for long-term operation.

C: Machines with vibration within this zone are normally considered unsatisfactory for long-term continuous operation. Generally, the machine may be operated for a limited period in this condition until a suitable opportunity arises for remedial action.

D: Vibration values within this zone are normally considered to be of sufficient severity to cause damage to the machine.

NOTE — Vibration values for reciprocating machines may tend to be more constant over the life of the machine than for rotating machines. Therefore zones A and B are combined in this table. In future, when more experience is accumulated, guide values to differentiate between zones A and B may be provided.

Annex B (informative)

Forms for vibration measurements on reciprocating machines

Vibration measurements on reciprocating machines Measurement record											Form 1		
B.1	General												
	Record No.: _____					Installation site: _____							
	Date: _____					Measured by: _____							
B.2	Details of reciprocating machine												
	Kind: Diesel engine/compressor ¹⁾					Function: driver/driven ¹⁾							
	Manufacturer: _____					Type/Serial No.: _____							
	Machine ID No.: _____					Configuration: in-line horizontal/vertical; Vee; opposed ¹⁾							
	Number of cylinders: _____					Working cycle: two/four stroke ¹⁾ ; single/double effect ¹⁾							
	Related speed: _____ r/min					Speed during measurement: _____ r/min							
	Related power: _____ kW					Power during measurement: _____ kW							
	Mounting: rigid/resilient ¹⁾ ; directly/on baseplate ¹⁾					Connection: rigid/flexible ¹⁾							
	Notes: _____												
B.3	Details of measuring system												
	Instrument type: _____					Make: _____							
	Transducer type: _____					Attachment: _____							
	Does the measuring system comply with the requirements of 4.1 of ISO 10816-6:1995; i.e. overall r.m.s. values 10 Hz to 1 000 Hz with accuracy $\pm 10\%$; 2 Hz to 10 Hz with accuracy $\begin{matrix} +10 \\ -20 \end{matrix} \%?$										Yes/No ¹⁾		
	Notes: _____												
B.4	Results												
	Sketch machine below: Designate measurement points in accordance with figures 1 to 3 of ISO 10816-6:1995.												
	Measurement values: Enter in form 2.												
	Measurement records, spectra, diagrams, etc. should be attached, giving points and directions of measurement, and the power and speed at the time of measurement, if applicable.												
Directions of measurements: related to crankshaft axis (see figures 1 to 3 of ISO 10816-6:1995) $x = \text{axial}; y = \text{horizontal-transverse}; z = \text{vertical}$													
1) Delete/supplement as appropriate.													

Vibration measurements on reciprocating machines										Form 2		
Measurement results												
Measurement point No. as sketch	Speed tr/min	Power kW	Measurement quantity: r.m.s. overall values (2 Hz à 1 000 Hz)									Notes
			Horizontal-transverse			Vertical			Axial			
			d μm M ¹⁾ C ¹⁾	v mm/s M ¹⁾ C ¹⁾	a m/s ² M ¹⁾ C ¹⁾	d μm M ¹⁾ C ¹⁾	v mm/s M ¹⁾ C ¹⁾	a m/s ² M ¹⁾ C ¹⁾	d μm M ¹⁾ C ¹⁾	v mm/s M ¹⁾ C ¹⁾	a m/s ² M ¹⁾ C ¹⁾	

1) Mark as appropriate: M = measured directly
C = calculated from frequency spectrum

Annex C (informative)

Vibration severity grade nomograph

The vibration nomograph given as figure C.1 shows a range of vibration severity grades. A multifrequency vibration system cannot easily be classified on a discrete frequency scale, therefore the limiting values for each grade are primarily presented in table 1. Machines with a multifrequency vibration should therefore be classified by comparing the measured overall values of displacement, velocity and acceleration with the values given in table 1.

Severity grades are obtained for each of the highest overall r.m.s. value of the displacement, velocity and acceleration measured on the main structure of the machine. The vibration severity grade of the machine is the highest of these three grades.

NOTE 4 If a machine is known from frequency analysis to have only one vibration frequency component present at a particular frequency, this may be classified directly using the nomograph, using only one of the parameters displacement velocity or acceleration.

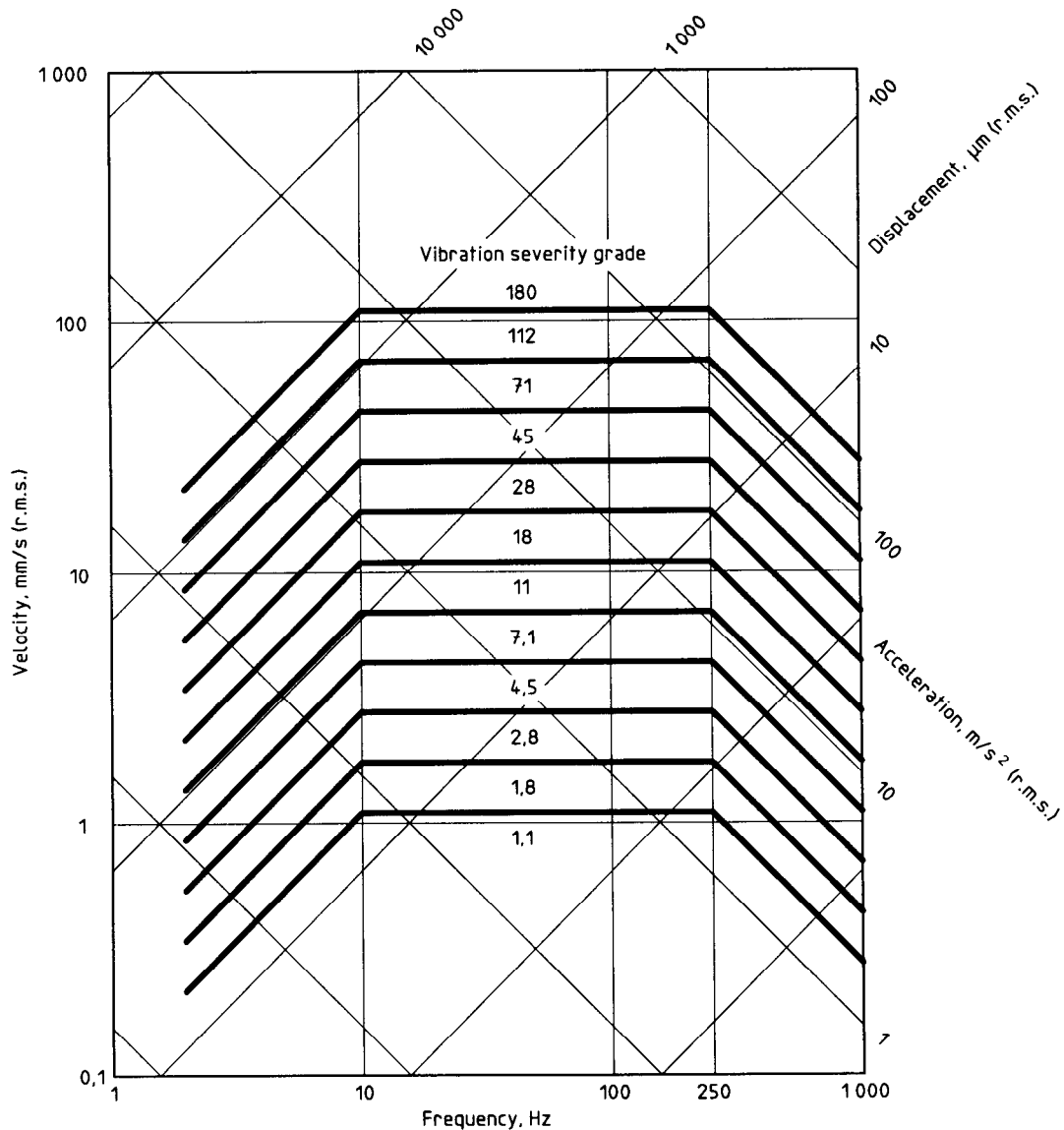


Figure C.1 — Vibration severity grade nomograph

Annex D

(informative)

Bibliography

- [1] ISO 2017:1982, *Vibration and shock — Isolators — Procedure for specifying characteristics*.
- [2] ISO 2954:1975, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity*.
- [3] ISO 4866:1990, *Mechanical vibration and shock — Vibration of buildings — Guidelines for the measurement of vibrations and evaluation of their effects on buildings*.
- [4] ISO 5348:1987, *Mechanical vibration and shock — Mechanical mounting of accelerometers*.
- [5] ISO 8528-9:1995, *Reciprocating internal combustion engine driven alternating current generating sets — Part 9: Measurement and evaluation of mechanical vibrations*.
- [6] ISO 10816-1:1995, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines*.

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Descriptors: vibration, machinery, piston machines, reciprocating engines, tests, vibration tests, acceptance testing, estimation, vibration severity.

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