INTERNATIONAL STANDARD

ISO
8041-1

First edition
2017-05

Human response to vibration — Measuring instrumentation —

Part 1:
General purpose vibration meters

Réponse des individus aux vibrations — Appareillage de mesure —

Partie 1: Instrument de mesure à usage général

Reference number
ISO 8041-1:2017(E)

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

This first edition cancels and replaces ISO 8041:2005, which has been technically revised. It also incorporates the Technical Corrigendum ISO 8041:2005/Cor. 1:2007. The following main changes have been made:

— addition of an Introduction explaining the reasons for this revision;

— addition of a validation test for one-off instruments;

— revision and simplification of the verification test;

— addition of Annex I, which gives example estimates of the instrumental measurement uncertainty;

— correction of errors in formulae, numbers and figures.

A list of parts in the ISO 8041 series can be found on the ISO website.

Introduction

Until 2005, when the previous edition of this document was published, measuring instrumentation for human response to vibration (vibration meters) normally consisted of a signal processing unit and a detachable vibration transducer. According to recent developments, however, part of the signal processing steps can be integrated in the transducer unit, so that the signal coming out of the transducer's sensing element and going into the signal conditioning unit is not accessible any more. These transducer units include, for example, IEPE and MEMS transducers.

Some of the test procedures specified in this document, however, presume that this point in the signal path is accessible (electrical input). Since such an input is not mandatory these tests can only be performed on a vibration meter having an electrical input or after some technical modifications to the instrumentation, e.g. internal access to signal paths. Or those tests can only be performed mechanically, which in certain cases requires modifications to some test procedures. Such modifications to test procedures, however, are beyond the present scope of this document.

Some of the test procedures specified in this document can only be performed if an electrical output is available, see for example 5.13. Since such an output is not mandatory these tests can only be performed on a vibration meter having an electrical output or after some technical modifications to the instrumentation, e.g. internal access to signal paths.

The verification test now specified in this document is practicable and has the objective of identifying an instrument which is adequately calibrated for the intended applications and is suitable for its purpose, at a cost reasonable for the calibration laboratory and affordable for the end user. Therefore, the verification test is strongly reduced in its extent compared to the full pattern evaluation, or validation, and only tests the most relevant characteristics of a vibration meter.

Human response to vibration — Measuring instrumentation —

Part 1: General purpose vibration meters

1 Scope

This document specifies the performance specifications and tolerance limits for instruments designed to measure vibration values, for the purpose of assessing human response to vibration. It includes requirements for pattern evaluation, or validation, periodic verification and *in situ* checks, and the specification of vibration calibrators for *in situ* checks.

Vibration instruments specified in this document can be single instruments, combinations of instrumentation or computer-based acquisition and analysis systems.

Vibration instruments specified in this document are intended to measure vibration for one or more applications, such as the following:

— hand-transmitted vibration (see ISO 5349-1);

— whole-body vibration (see ISO 2631-1, ISO 2631-2 and ISO 2631-4);

— low-frequency whole-body vibration in the frequency range from 0,1 Hz to 0,5 Hz (see ISO 2631-1).

Vibration instruments can be designed for measurement according to one or more of the frequency weightings defined within each of these applications.

Three levels of performance testing are defined in this document:

a) pattern evaluation or validation:

    1) pattern evaluation, i.e. a full test of the instrument against the specifications defined in this document;

    2) validation of one-off instruments, i.e. a limited set of tests of an individual vibration measuring system against the relevant specifications defined in this document;

b) periodic verification, i.e. an intermediate set of tests designed to ensure that an instrument remains within the required performance specification;

c) *in situ* checks, i.e. a minimum level of testing required to indicate that an instrument is likely to be functioning within the required performance specification.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 2631-1, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements*

ISO 2631-2, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 2: Vibration in buildings (1 Hz to 80 Hz)*

ISO 2631-4:2001, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems*

ISO 5347 (all parts), *Methods for the calibration of vibration and shock pick-ups*

ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*

ISO 5349-1:2001, *Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 1: General requirements*

ISO 16063 (all parts), *Methods for the calibration of vibration and shock transducers*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

IEC 61000-4-2:2008, *Electromagnetic compatibility (EMC) — Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3:2006, *Electromagnetic compatibility (EMC) — Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) — Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-6-2:2005, *Electromagnetic compatibility (EMC) — Part 6-2: Generic standards – Immunity for industrial environments*

CISPR 22:2008, *Information technology equipment — Radio disturbance characteristics — Limits and methods of measurement*

3   Terms, definitions and symbols

3.1   Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041, ISO/IEC Guide 99 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1   General

3.1.1.1
vibration acceleration
component of acceleration, where the axis of measurement is specified by application standards

3.1.1.2
band-limiting frequency weighting
component of a frequency weighting defined by the high- and low-pass band-limiting filters

3.1.1.3
band-limited frequency range
frequency range defined by the band-limiting component of a frequency weighting

3.1.1.4
nominal frequency range
frequency range of interest, as defined in the relevant measurement standard

3.1.1.5
linear operating range
range between lower and upper boundaries, on each measurement range, over which the linearity errors do not exceed the applicable tolerance limits specified in this document

3.1.1.6
overload
condition that occurs when the upper boundary of the linear operating range is exceeded

3.1.1.7
under-range
condition that occurs when the vibration value is below the lower boundary of the linear operating range

3.1.1.8
reference measurement range
level range specified for testing the characteristics of the vibration instrumentation

Note 1 to entry: This range is used for measuring the reference vibration.

3.1.1.9
reference vibration signal
sinusoidal vibration signal, the magnitude and frequency of which are specified in this document for testing the electromechanical performance of a human-vibration meter

Note 1 to entry: Different reference vibration signals are specified according to the application of the instrumentation.

3.1.1.10
calibration check frequency
frequency specified for providing a check of the vibration sensitivity of the instrument

3.1.1.11
tone burst
one or more complete cycles of a sinusoidal signal that start and end at a zero crossing of the waveform

3.1.1.12
signal burst
one or more complete cycles of a periodic signal (such as saw tooth) that start and end at a zero crossing of the waveform

3.1.1.13
vibration measuring instrumentation
combination of a vibration transducer, signal processor and display, being any single instrument, or a collection of instruments, which is/are capable of measuring parameters relating to human response to vibration

Note 1 to entry: See Figures 1 and 2.

3.1.1.14
instrument documentation
instruction manual, operating procedure or other documentation provided for the use of users of the vibration measurement instrument

3.1.2 Frequency-weighted values

3.1.2.1
time-averaged weighted acceleration value
frequency-weighted root-mean-square (r.m.s.) vibration acceleration value in a specified axis, a_w, in metres per second squared or radians per second squared, as defined by the expression

$$a_w = \left(\frac{1}{T} \int_0^T a_w^2(\xi) \, d\xi \right)^{1/2}$$

where

$a_w(\xi)$ is the translational or rotational, frequency-weighted vibration acceleration in a specified direction or around a specified axis as a function of the instantaneous time, ξ in metres per second squared (m/s^2) or radians per second squared (rad/s^2), respectively;

T is the duration of the measurement.

3.1.2.2
time-averaged weighted acceleration level
frequency-weighted r.m.s. vibration acceleration level expressed in decibels, as defined by

$$L_w = 20 \lg \frac{a_w}{a_0} \, dB$$

where

a_w is the frequency-weighted r.m.s. acceleration value;

a_0 is the reference acceleration (in ISO 1683 for translational acceleration defined as $10^{-6} \, m/s^2$).

3.1.2.3
running r.m.s. acceleration value
frequency-weighted running r.m.s. vibration acceleration, in metres per second squared, defined by the expression

$$a_{w,\theta}(t) = \left(\frac{1}{\theta} \int_{t-\theta}^t a_w^2(\xi) \, d\xi \right)^{1/2}$$

where

$a_w(\xi)$ is the frequency-weighted instantaneous vibration acceleration at time ξ, in metres per second squared or radians per second squared (rad/s^2), respectively;

θ is the integration time of the measurement;

t is the instantaneous time.

Note 1 to entry: Exponential averaging may be used for the running r.m.s. method, as an approximation of the linear averaging. The exponential averaging is defined as follows:

$$a_{w,\tau}(t) = \left(\frac{1}{\tau} \int_{-\infty}^t a_w^2(\xi) \exp\left(\frac{\xi - t}{\tau} \right) d\xi \right)^{1/2}$$

where τ is the time constant.

3.1.2.4
maximum transient vibration value
MTVV
maximum value of the running r.m.s. vibration acceleration value when the integration time is equal to 1 s

3.1.2.5
motion sickness dose value
MSDV
integral of the squared frequency-weighted instantaneous vibration acceleration $a_\text{w}(t)$ in m/s^{1,5} as defined by the expression

$$\text{MSDV} = \left(\int_0^\Phi a_\text{w}^2\left(\xi\right)\text{d}\xi \right)^{1/2}$$

where Φ is the total period during which motion could occur

Note 1 to entry: The motion sickness dose value can be obtained from the frequency-weighted r.m.s. vibration acceleration through multiplication by $\Phi^{1/2}$.

Note 2 to entry: For measurement instrumentation, the exposure period, Φ, is likely to be assumed to be equal to the measurement period, T, unless otherwise indicated.

3.1.2.6
vibration dose value
VDV
integral of the fourth power of the frequency-weighted instantaneous vibration acceleration $a_\text{w}(t)$ in m/s^{1,75} as defined by the expression

$$\text{VDV} = \left(\int_0^\Phi a_\text{w}^4\left(\xi\right)\text{d}\xi \right)^{1/4}$$

where Φ is the total (daily) period for which vibration exposure occurs

Note 1 to entry: The vibration dose value is more sensitive to peaks than is the r.m.s. value.

Note 2 to entry: For measurement instrumentation, the exposure period, Φ, is likely to be assumed to be equal to the measurement period, T, unless otherwise indicated.

3.1.2.7
vibration total value
combined vibration from three axes of translational vibration, as defined by the expression

$$a_\text{wv} = \sqrt{k_x^2\, a_\text{w}^2{}_x + k_y^2\, a_\text{w}^2{}_y + k_z^2\, a_\text{w}^2{}_z}$$

where

$a_\text{w}x$, $a_\text{w}y$ and $a_\text{w}z$ are the weighted vibration values in the three orthogonal axes x, y and z;

k_x, k_y and k_z are multiplying constants whose values depend on the measurement application

3.1.2.8
peak vibration value
maximum modulus of the instantaneous (positive and negative) peak values of the frequency-weighted acceleration

3.1.2.9
crest factor
parameter for a measurement period, given by the peak vibration value divided by the r.m.s. vibration value, with both values having the same frequency weighting

3.2 Symbols

For the purposes of this document, the following symbols and abbreviated terms apply.

a_w	time-averaged frequency-weighted single-axis vibration acceleration
$a_w(t)$, $a_w(\xi)$	instantaneous frequency-weighted translational or rotational single-axis acceleration at time t, or time ξ
f	frequency
H	overall frequency weighting function
k_i	multiplying constants applied to the whole-body frequency-weighted acceleration value for axis i
n	one-third-octave band number
s	variable of the Laplace transform
t or ξ	instantaneous time
T	measurement duration
W_x	frequency weighting
Φ	exposure duration
ΔP_{max}	maximum peak value deviation
$\Delta\varphi$	phase error
$\Delta\vartheta$	phase delay time difference
τ	exponential averaging time constant
θ	linear averaging time
MSDV	motion sickness dose value
MTVV	maximum transient vibration value
VDV	vibration dose value
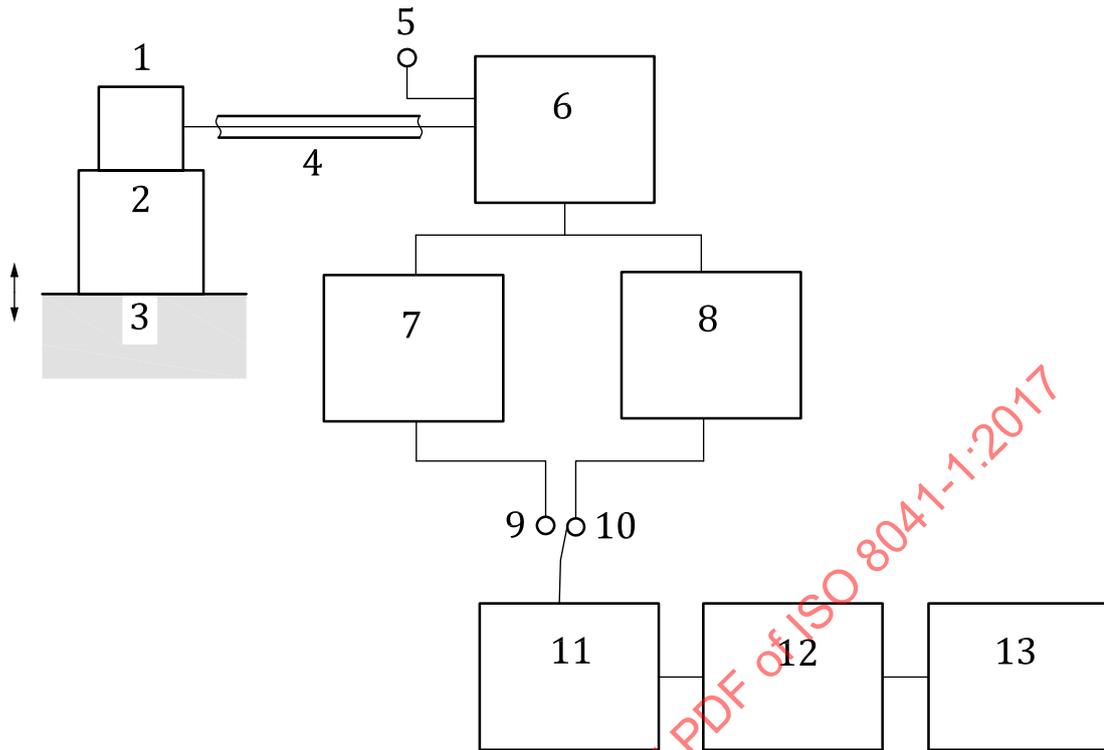
Key

1	transducer	8	frequency weighting — including band-limiting
2	mounting system	9	band-limited output
3	vibrating surface	10	frequency-weighted output
4	cable	11	time weighting
5	electrical input	12	additional processing
6	signal conditioning	13	display
7	band limiting		

Figure 1 — Example of the basic functional path of a vibration measurement instrument or measurement system — time-domain signal processing
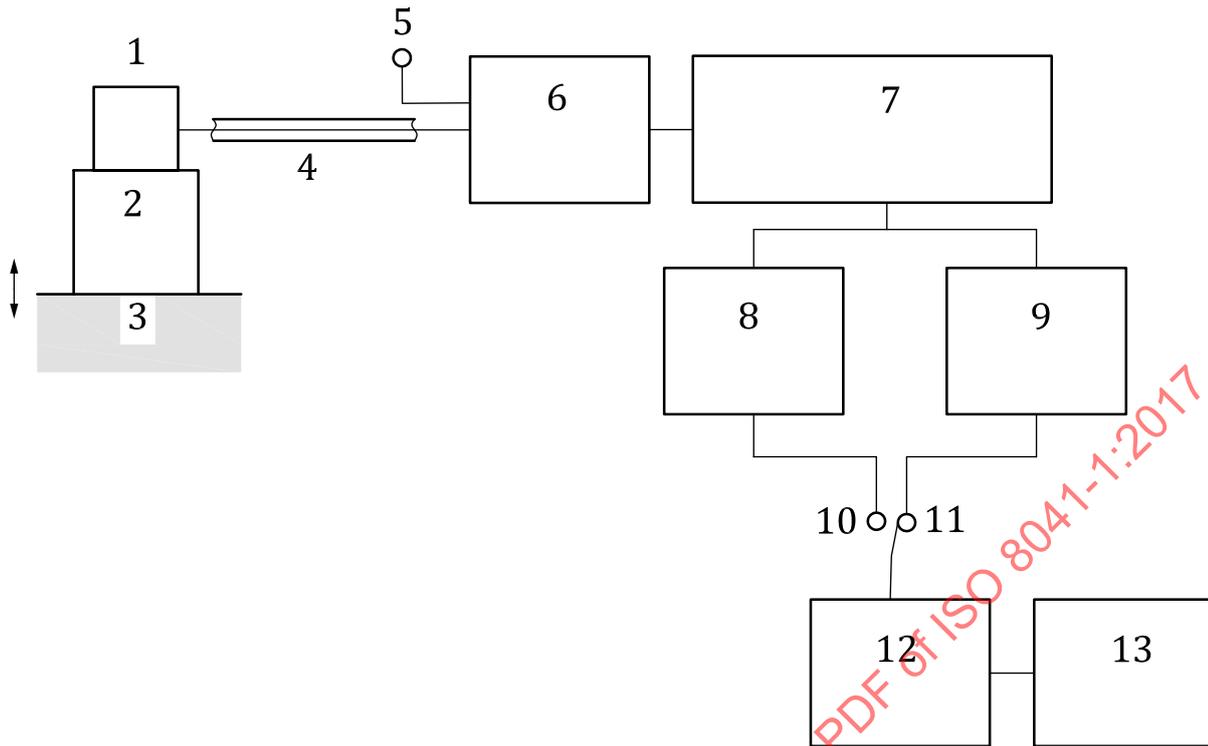
Key

1	transducer	8	band limiting (calculation)
2	mounting system	9	frequency weighting — including band limiting (calculation)
3	vibrating surface	10	band-limited output
4	cable	11	frequency-weighted output
5	electrical input	12	accumulation of frequency bands
6	signal conditioning	13	display
7	frequency analysis time weighting time averaging		

Figure 2 — Example of the basic functional path of a vibration measurement instrument or measurement system — frequency-domain signal processing (not applicable to VDV processing)

4 Reference environmental conditions

Reference environmental conditions for specifying the performance of a vibration meter are

— air temperature: 23 °C, and

— relative humidity: 50 %.

5 Performance specifications

5.1 General characteristics

The performance specifications of this clause apply under the reference environmental conditions.

As a minimum, human-vibration measuring instrumentation shall provide a means of displaying

— time-averaged weighted vibration acceleration value over the measurement duration, a_w,

— time-averaged band-limited vibration acceleration value over the measurement duration, and

— measurement duration, T.

The human-vibration measuring instrument shall also provide a means of indicating whether an overload occurred at any time within the measurement duration.

The human-vibration measuring instrument shall provide a method for setting and adjusting the vibration sensitivity.

Human-vibration measuring instruments may contain any or all of the design features for which performance specifications are given in this document. An instrument shall conform to the applicable performance specifications for those design features that are provided.

If the instrument has more than one measurement range, the instrument documentation shall describe the measurement ranges that are included and the operation of the measurement range control. The instrument documentation shall also identify which is the reference measurement range.

The reference vibration signal values and frequencies are given in Table 1.

Table 1 — Reference vibration values and frequencies

Application	Fre-quency weighting	Reference	Nominal frequency range Hz	Reference		Weighting factor at reference frequency	Weighted acceleration at reference frequency and r.m.s. acceleration value m/s²
				Frequency	r.m.s. accelera-tion value m/s²		
Hand-transmitted	W_h	Table B.6	8 to 1 000	500 rad/s (79,58 Hz)	10	0,202 0	2,020
Whole-body	W_b	Table B.1	0,5 to 80	100 rad/s (15,915 Hz)	1	0,812 6	0,812 6
	W_c	Table B.2				0,514 5	0,514 5
	W_d	Table B.3				0,126 1	0,126 1
	W_e	Table B.4				0,062 87	0,062 87
	W_j	Table B.7				1,019	1,019
	W_k	Table B.8				0,771 8	0,771 8
	W_m	Table B.9	1 to 80			0,336 2	0,336 2
Low-frequency whole-body	W_f	Table B.5	0,1 to 0,5	2,5 rad/s (0,397 9 Hz)	0,1	0,388 8	0,038 88

If the instrument is capable of measuring the maximum (e.g. MTVV) and peak vibration values, a "hold" function shall be provided. The instrument documentation shall describe the operation of the hold feature and the method for clearing a display that is held.

Many of the specifications and tests in this document require the application of electrical signals substituting for the signal from the vibration transducer. The instrument documentation shall specify a means for substituting an electrical signal, equivalent to the signal from the vibration transducer, for performing electrical tests on the complete instrument without the vibration transducer. If appropriate,

the instrument documentation may describe alternative methods to test the specified operations of the human-vibration meter.

NOTE   The manufacturer of the human-vibration meter is free to provide an input test point, or a dummy vibration transducer of specified electrical impedance (termination), or an equivalent input adapter (electrical or non-electrical) to perform electrical tests on the instrument.

The instrument documentation shall specify the maximum peak vibration at the vibration transducer and the maximum peak-to-peak signal (e.g. charge or voltage) that can be applied at the electrical input facility. The maximum vibration value and the maximum peak-to-peak voltage shall not cause damage to the instrument.

The tolerance limits given in this document include the associated expanded uncertainties of measurement, calculated for a coverage factor of 2, corresponding to a coverage probability of approximately 95 %, in accordance with the guidance given in ISO/IEC Guide 98-3. Guidelines for estimating instrumental measurement uncertainty are provided in Annex I.

5.2   Display of signal magnitude

5.2.1   General

For instruments that can display more than one measurement quantity, a means shall be provided to ascertain clearly the measurement quantity that is being displayed, preferably indicated by standard abbreviations or letter symbols.

The quantities that can be displayed by the human-vibration meter shall be described in the instrument documentation, along with a description of the corresponding indications on each display device.

The instrument shall display the frequency-weighted acceleration values. Optionally, it may also display the frequency-weighted acceleration value multiplied by a factor k, as defined in ISO 2631-1. Where multiplying factors are used, this shall be clearly indicated on the instrument and the instrument shall be capable of displaying the multiplying factors.

Where a combined axis output is displayed (e.g. vibration total value, 3.1.2.7), the instrument shall be capable of displaying the values of the multiplying factors used.

When results of a measurement are provided at a digital output, the instrument documentation shall describe the method for transferring or downloading the digital data to an external data storage or display device. The instrument documentation shall identify the computer software as well as the hardware for the interface. Internationally standardized interface bus compatibility is recommended.

Each alternative device for displaying the signal value, stated in the instrument documentation as conforming to the specifications of this document, is considered an integral part of the instrument. Each such alternative device shall be included as part of the components required for conformance to the performance specifications in this clause and the applicable environmental specifications of Clause 7. Examples of alternative display devices include level recorders or computers with monitor screens.

For an instrument that uses a display device with a range less than the linear operating range specified in 5.7, the instrument documentation shall describe a means to test the linearity beyond the limits of the indicator range.

5.2.2   Resolution and refresh rate

The display device(s) specified in the instrument documentation shall permit measurements with a resolution of not more than 1 % of the indicated value.

If an instrument only has an analogue, or simulated analogue, display device that provides a continuous indication, the display shall be a logarithmic display of the vibration value. The range of the analogue display device shall include a display of at least 2 decades, with each decade being at least 10 mm wide.

Where the display range does not encompass the whole of the linearity range of the instrument, then the display range shall be switchable to allow for the whole of the linearity range to be viewed.

If a digital indicator is provided, and the measurement quantity displayed is a vibration parameter, the display shall be updated at regular time intervals. The time interval between updates shall be appropriate to the measurement being displayed. The extent of the range of a digital display shall be at least sufficient to cover the linear operating range.

For instruments with digital display devices updated at periodic intervals, the indication at each display update shall be the value of the user-selected quantity at the time of the display update. Other modes of indication at the time of the display update may be identified in the instrument documentation and, if so, the operation of such modes shall be explained in the instrument documentation. The instrument documentation shall state which modes conform to the specifications of this document and which do not conform.

5.2.3 Stabilization, measurement start and display times

Within the prevailing environmental conditions, the time interval required for stabilizing and being ready to use shall be no greater than 2 min from switching on the instrument.

The display shall indicate when the instrument is ready for use following switch-on, range change or changes to filter selection.

The time between a user initiating a measurement and the start of that measurement shall be no greater than 0,5 s.

NOTE   This can require an initialization procedure, particularly for low-frequency whole-body vibration: an operating phase prior to measurement initiation that ensures that the instrument has settled following the end of a previous measurement.

Prior to a measurement result being available, the instrument display shall clearly indicate whether a measurement is in progress, or whether an initialization stage is underway.

5.3   Electrical output

If an AC electrical output is provided, the instrument documentation shall state the characteristics of the output signals. The characteristics shall include

— the range of peak-to-peak voltages, which shall be not less than 1 V,

— the internal electrical impedance at the output,

— the minimum load impedance, and

— the frequency weightings applied to the output signals.

Connection of passive impedance without stored electrical energy, including a short circuit, to the electrical output shall not affect any measurement in progress by more than 2 %.

5.4   Vibration sensitivity

The instrument documentation shall specify at least one model of field vibration calibrator as a means to check and maintain the mechanical sensitivity of the human-vibration instrument. The field vibration calibrator shall conform to the specifications given in Annex A.

The instrument documentation for the vibration instrument shall describe the procedure for adjusting the indicated vibration to conform to the specifications in this document by application of the specified field vibration calibrator. The adjustment shall apply to the models of vibration transducers recommended in the instrument documentation for use with the vibration meter. The adjustment shall also apply to any cables, connectors and other accessories provided by the manufacturer of the vibration meter for connecting a vibration transducer to the vibration meter.

5.5 Accuracy of indication at reference frequency under reference conditions

The requirements for tolerance of the displayed results are given in Table 2. The tolerance of indication is specified at the appropriate reference frequency and reference vibration value specified in Table 1 with the instrument switched to the reference measurement range, with sinusoidal mechanical vibration applied to the base of the vibration transducer or specified mounting device. The requirements apply to all frequency weightings specified in this document and after applying adjustments described in 5.4 and after the specified stabilization time interval has elapsed.

Table 2 — Tolerances of indication at reference frequency and reference vibration value

Parameter	Tolerance
Tolerance of indication at the reference frequency under reference environmental conditions	±4 % for hand-transmitted and whole-body vibration
	±5 % for low-frequency whole-body vibration
The difference between the indicated value of any frequency-weighted measurement quantity and the indicated value of the corresponding band-limiting measurement multiplied by the appropriate weighting factor (for a steady sinusoidal input vibration signal at the reference frequency and reference vibration value)	±3 %
The difference between the indication of the running r.m.s. vibration value with a band-limiting frequency weighting, and the indication of the band-limiting frequency-weighted vibration value with the linear time-averaged r.m.s. value over any measurement time (for a steady sinusoidal input vibration signal at the reference frequency and reference vibration value)	±2 %

5.6 Frequency weightings and frequency responses

5.6.1 Parameters

A human-vibration meter shall have one or more of the frequency weighting or weightings listed in Table 1, including the appropriate band-limiting weightings. The frequency weightings are defined by Formulae (1) to (5) and the parameters given in Table 3.

Table 3 — Parameters and transfer functions of the frequency weightings

Weighting	Band-limiting				a-v transition			Upward step				Gain
	f_1 Hz	Q_1	f_2 Hz	Q_2	f_3 Hz	f_4 Hz	Q_4	f_5 Hz	Q_5	f_6 Hz	Q_6	K
W_b	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	16	16	0,55	2,5	0,9	4	0,95	1,024
W_c	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	8	8	0,63	∞	1	∞	1	1
W_d	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	2	2	0,63	∞	1	∞	1	1
W_e	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	1	1	0,63	∞	1	∞	1	1
W_f	0,08	$1/\sqrt{2}$	0,63	$1/\sqrt{2}$	∞	0,25	0,86	0,062 5	0,80	0,10	0,80	1
W_h	$10^{8/10}$	$1/\sqrt{2}$	$10^{31/10}$	$1/\sqrt{2}$	$100/(2\pi)$	$100/(2\pi)$	0,64	∞	1	∞	1	1
NOTE 1 For weighting W_b, ISO 2631-4:2001, Table A.1, rounds the value of parameter Q_1 to two decimal places. The parameter specified here is the exact value.												
NOTE 2 For weighting W_h, ISO 5349-1:2001, Table A.1, rounds the values of parameters f_1, f_2, f_3 and f_4 to five significant figures and parameter Q_1 to two decimal places. The parameters specified here are the exact values.												

Table 3 *(continued)*

Weight-ing	Band-limiting				a-v transition			Upward step				Gain
	f_1 Hz	Q_1	f_2 Hz	Q_2	f_3 Hz	f_4 Hz	Q_4	f_5 Hz	Q_5	f_6 Hz	Q_6	K
W_j	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	∞	∞	1	3,75	0,91	5,32	0,91	1
W_k	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	12,5	12,5	0,63	2,37	0,91	3,35	0,91	1
W_m	$10^{-0,1}$	$1/\sqrt{2}$	100	$1/\sqrt{2}$	$1/(0{,}028 \times 2\pi)$	$1/(0{,}028 \times 2\pi)$	0,5	∞	1	∞	1	1

NOTE 1   For weighting W_b, ISO 2631-4:2001, Table A.1, rounds the value of parameter Q_1 to two decimal places. The parameter specified here is the exact value.

NOTE 2   For weighting W_h, ISO 5349-1:2001, Table A.1, rounds the values of parameters f_1, f_2, f_3 and f_4 to five significant figures and parameter Q_1 to two decimal places. The parameters specified here are the exact values.

The angular frequencies ω_1, ..., ω_6 (given by $\omega_i = 2\pi f_i$ where f_i are the frequencies f_1, ..., f_6 in Table 3) and the resonant quality factors Q_1, Q_2, Q_4, Q_5 and Q_6 are parameters of the transfer functions in Formulae (1) to (5) which determine the overall vibration acceleration frequency weightings. The overall frequency weighting function is a product of band-limiting, a-v transition and upward-step filters.

5.6.2   Band-limiting filter

The band-limiting element is a combination of high- and low-pass second-order Butterworth filter characteristics. These components are defined as shown by Formulae (1) and (2):

a)   High pass

$$H_h\left(s\right) = \frac{1}{1 + \dfrac{\omega_1}{Q_1 s} + \left(\dfrac{\omega_1}{s}\right)^2} \tag{1}$$

b)   Low pass

$$H_l\left(s\right) = \frac{1}{1 + \dfrac{s}{Q_2 \omega_2} + \left(\dfrac{s}{\omega_2}\right)^2} \tag{2}$$

The product $H_h(s) \cdot H_l(s)$ represents the band-limiting transfer function.

5.6.3   a-v transition filter

The a-v transition filter is proportional to acceleration at lower frequencies and to velocity at higher frequencies, as shown by Formula (3):

$$H_t\left(s\right) = \frac{\left(1 + \dfrac{s}{\omega_3}\right)K}{1 + \dfrac{s}{Q_4 \omega_4} + \left(\dfrac{s}{\omega_4}\right)^2} \tag{3}$$

NOTE $H_t(s) = 1$ when both f_3 and f_4 (ω_3 and ω_4) equal infinity.

5.6.4   Upward-step filter

The upward-step filter has a steepness of approximately 6 dB per octave and is proportional to jerk, as shown by Formula (4):

$$H_s\left(s\right) = \frac{1 + \dfrac{s}{Q_5\omega_5} + \left(\dfrac{s}{\omega_5}\right)^2}{1 + \dfrac{s}{Q_6\omega_6} + \left(\dfrac{s}{\omega_6}\right)^2} \left(\dfrac{\omega_5}{\omega_6}\right)^2 \tag{4}$$

NOTE $H_s(s) = 1$ when both f_5 and f_6 (ω_5 and ω_6) equal infinity.

5.6.5   Overall frequency weighting

The overall frequency weighting function for each weighting W_x is the product of band-limiting, a-v transition and upward-step filters, as shown by Formula (5):

$$H(s) = H_h(s) \cdot H_l(s) \cdot H_t(s) \cdot H_s(s) \tag{5}$$

The most common interpretation of these formulae is in the frequency domain, where they describe the modulus (magnitude) and phase of the frequency weightings as functions of the imaginary angular frequency $s = \mathrm{j}2\pi f$.

NOTE 1   Sometimes the letter p is used instead of s.

NOTE 2 s can be interpreted as the variable of the Laplace transform.

The tables and weighting curves given in Annex B illustrate the magnitude and phase of the frequency weightings defined by Formulae (1) to (5) and Table 3, as functions of frequency f.

If a human-vibration meter provides one or more optional frequency responses, the instrument documentation shall state the design-goal frequency response and the tolerance limits that are maintained around the design goal(s). If an optional frequency response is specified in an International Standard, the design-goal frequency response shall be as specified in that International Standard.

The filters defined by Table 3 and Formulae (1) to (5) may be realized by combinations of simple analogue filters. Annex C provides an example of how the frequency weightings can be realized digitally in the time and frequency domains.

5.6.6   Tolerances

The tolerances on the frequency weightings are given in Tables 4 and 5. The tolerance limits in Table 5 apply to the weightings, including the corresponding band-limiting weightings, on all measurement ranges. Tolerance limits include the applicable maximum expanded uncertainties of measurement.

The phase response of vibration instrumentation is critical to measured parameters not based on the r.m.s. average value, e.g. peak, MTVV and VDV. The phase response is given by Formulae (1) to (5). However, the errors in measurement due to errors in the phase response are dependent on the rate of

change in phase error with frequency, rather than the absolute phase error itself. For this reason, the phase response is assessed using the characteristic phase deviation, $\Delta\varphi_0$, defined as by Formula (6):

$$\Delta\varphi_0 = \left| \frac{f_n \Delta\varphi_{n+1} - f_{n+1} \Delta\varphi_n}{f_{n+1} - f_n} \right| \tag{6}$$

where

f_n is the centre frequency at one-third-octave band number n;

$\Delta\varphi_n$ is the phase error at frequency corresponding to one-third-octave band number n.

Table 4 — Transition frequencies for frequency weighting tolerances

Weight-ing	Tolerance transition frequencies Hz			
	f_{t1}	f_{t2}	f_{t3}	f_{t4}
W_b	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_c	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_d	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_e	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_f	$10^{-13/10}$ (0,05012)	$10^{-9/10}$ (0,1259)	$10^{-4/10}$ (0,3981)	$10^{0/10}$ (1)
W_h	$10^{6/10}$ (3,981)	$10^{10/10}$ (10)	$10^{29/10}$ (794,3)	$10^{33/10}$ (1995)
W_j	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_k	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_m	$10^{-3/10}$ (0,5012)	$10^{1/10}$ (1,259)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)

Table 5 — Tolerances on frequency weightings

Frequency f	Magnitude tolerance	Characteristic phase deviation [a] $\Delta\varphi_0$
$f \leq f_{t1}$	+26 %, −100 %	±∞
$f_{t1} < f < f_{t2}$	+26 %, −21 %	±12°
$f_{t2} \leq f \leq f_{t3}$	+12 %, −11 %	±6°
$f_{t3} < f < f_{t4}$	+26 %, −21 %	±12°
$f_{t4} \leq f$	+26 %, −100 %	±∞
[a] Characteristic phase deviation tolerances only apply to instruments that provide measurement parameters that are not based on r.m.s. values.		

5.7 Amplitude linearity

Over the entire measurement range, the indicated signal value shall be a linear function of the mechanical vibration value at the vibration transducer. This design goal applies at any frequency within the frequency range of the instrument at any frequency weighting or frequency response provided. The

linearity specifications apply to the whole instrument, including the transducer, and to all measured vibration parameters.

Over the full extent of all the measurement ranges, the linearity error shall not exceed 6 % of the input value. On the reference measurement range and at the reference frequency, the linear operating range shall be at least 60 dB.

NOTE   For hand-arm vibration, a greater linearity range can be necessary for the measurement of highly impactive vibration signals.

The instrument documentation shall state the range of vibration values within which the linearity error does not exceed 6 % without indication of under-range or overload. This requirement applies for steady sinusoidal signals at any frequency in the nominal frequency range.

For instruments with multiple and manually selected measurement ranges, the overlap of vibration values indicated on adjacent measurement ranges shall be at least 40 dB.

For each measurement range, the instrument documentation shall state the range of vibration values that can be measured without under-range or overload, i.e. the lower and upper boundaries of the linear operating ranges.

5.8   Instrument noise

For time-averaged frequency-weighted vibration, the instrument documentation shall state the typical indications that will be observed on the display device when the vibration transducer of the instrument is fitted to a non-vibrating object that does not add significantly to the indications. The indications shall correspond to the total inherent noise from the combination of the recommended vibration transducer(s) and the other components in the human-vibration meter, at least for reference environmental conditions.

5.9   Signal-burst response

The specification of human-vibration instruments for the response to signal bursts is given in terms of the response to saw-tooth signals at the reference frequency.

The saw-tooth test signal is illustrated in Figure 3. The tests are carried out using saw-tooth burst with the characteristics given in Table 6. The responses given in Tables 7 to 9 are relative to a 1 m/s^2 amplitude signal and shall be multiplied by the amplitude of the actual test signal.

NOTE 1   The response to the saw-tooth signal burst is determined by digital simulation of the filter characteristics.

NOTE 2   The saw-tooth wave shape has been chosen to ensure that the signal burst contains combinations of frequencies with known phase relationships. The saw-tooth burst test therefore ensures that the relative phase response of the frequency weighting at different frequencies is tested.
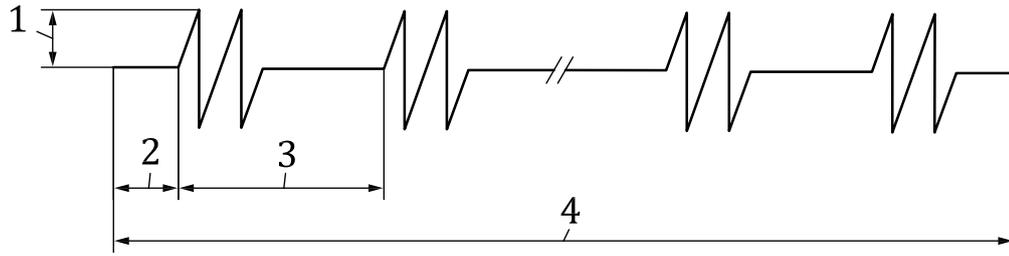
Key
1   amplitude
2   start time
3   repeat time
4   duration

Figure 3 — Saw-tooth burst test signal (2-cycle bursts illustrated)

Table 6 — Saw-tooth signal burst test signal characteristics

Application	Weighting	Angular frequency	Start time	Number of cycles	Repeat time	Duration
		rad/s	s		s	s
Hand-arm	W_h	500 (79,58 Hz)	0,2		2	12
Whole-body	W_b, W_c, W_d, W_e, W_j, W_k, W_m	100 (15,915 Hz)	1	1, 2, 4, 8, 16	10	60
Low-frequency whole-body	W_f	2,5 (0,3979 Hz)	40		400	2 400

Table 7 — Saw-tooth signal burst response for hand-arm vibration measurements

Weighting	Number of saw-tooth cycles per burst	r.m.s. value	Tolerance %
Band limiting	1	0,044 8	10
	2	0,063 3	10
	4	0,089 5	10
	8	0,127	10
	16	0,179	10
	Continuous	0,565	10
W_h	1	0,010 3	10
	2	0,013 3	10
	4	0,016 8	10
	8	0,022 4	10
	16	0,030 9	10
	Continuous	0,094 6	10

Table 8 — Saw-tooth signal burst response for whole-body vibration measurements

Weighting	Number of saw-tooth cycles per burst	r.m.s. value	Toler-ance %	VDV	Toler-ance %	MTVV linear	Toler-ance %	MTVV expo-nential	Toler-ance %
Band limiting	1	0,043 3	10	0,498	12	0,137	10	0,135	10
	2	0,061 2	10	0,593	12	0,193	10	0,188	10
	4	0,086 5	10	0,705	12	0,274	10	0,258	10
	8	0,122	10	0,838	12	0,387	10	0,344	10
	16	0,173	10	0,996	12	0,547	10	0,437	10
	Continu-ous	0,546	10	1,77	12	0,547	10	0,549	10
W_b	1	0,031 4	10	0,342	12	0,099 1	10	0,096 8	10
	2	0,043 5	10	0,403	12	0,137	10	0,132	10
	4	0,061 4	10	0,482	12	0,194	10	0,182	10
	8	0,086 7	10	0,575	12	0,274	10	0,243	10
	16	0,123	10	0,685	12	0,387	10	0,309	10
	Continu-ous	0,387	10	1,22	12	0,388	10	0,388	10
W_c	1	0,022 2	10	0,244	12	0,070 3	10	0,068 4	10
	2	0,029 2	10	0,275	12	0,092 3	10	0,088 5	10
	4	0,039 7	10	0,318	12	0,126	10	0,117	10
	8	0,055	10	0,374	12	0,174	10	0,153	10
	16	0,077	10	0,445	12	0,243	10	0,192	10
	Continu-ous	0,24	10	0,788	12	0,243	10	0,242	10
W_d	1	0,006 69	10	0,077 9	12	0,021 2	10	0,019 7	10
	2	0,009 06	10	0,085 2	12	0,028 6	10	0,026 4	10
	4	0,011 6	10	0,092 3	12	0,036 6	10	0,033	10
	8	0,014 8	10	0,101	12	0,046 9	10	0,04	10
	16	0,019 7	10	0,115	12	0,061 1	10	0,048 1	10
	Continu-ous	0,059	10	0,197	12	0,061 1	10	0,059 4	10
W_e	1	0,003 42	10	0,040 9	12	0,010 8	10	0,009 92	10
	2	0,004 78	10	0,045 2	12	0,015 1	10	0,013 5	10
	4	0,006 37	10	0,049 3	12	0,020 1	10	0,017 6	10
	8	0,008 16	10	0,053 5	12	0,025 5	10	0,021 4	10
	16	0,010 2	10	0,059 2	12	0,031 1	10	0,024 4	10
	Continu-ous	0,029 5	10	0,098 7	12	0,031 1	10	0,029 7	10
W_j	1	0,043 5	10	0,517	12	0,138	10	0,135	10
	2	0,0616	10	0,609	12	0,195	10	0,189	10
	4	0,0874	10	0,723	12	0,277	10	0,261	10
	8	0,124	10	0,859	12	0,392	10	0,349	10
	16	0,175	10	1,02	12	0,554	10	0,443	10
	Continu-ous	0,554	10	1,81	12	0,555	10	0,557	10

Table 8 *(continued)*

Weighting	Number of saw-tooth cycles per burst	r.m.s. value	Toler-ance %	VDV	Toler-ance %	MTVV linear	Toler-ance %	MTVV expo-nential	Toler-ance %
W_k	1	0,0299	10	0,323	12	0,094 4	10	0,092 2	10
	2	0,0411	10	0,38	12	0,13	10	0,125	10
	4	0,0577	10	0,455	12	0,182	10	0,171	10
	8	0,0814	10	0,543	12	0,257	10	0,228	10
	16	0,115	10	0,648	12	0,363	10	0,289	10
	Continu-ous	0,362	10	1,15	12	0,364	10	0,363	10
W_m	1	0,0149	10	0,165	12	0,047 2	10	0,045 6	10
	2	0,0197	10	0,185	12	0,062 3	10	0,059 4	10
	4	0,0264	10	0,211	12	0,083 6	10	0,077 5	10
	8	0,0363	10	0,247	12	0,115	10	0,101	10
	16	0,0507	10	0,294	12	0,16	10	0,126	10
	Continu-ous	0,158	10	0,52	12	0,16	10	0,159	10

Table 9 — Saw-tooth signal burst response for low-frequency whole-body vibration measurements

Weighting	Number of saw-tooth cycles per burst	r.m.s. value	Tolerance %	MSDV	Tolerance %
Band limiting	1	0,034 1	10	1,671	10
	2	0,048 7	10	2,386	10
	4	0,069	10	3,38	10
	8	0,098 2	10	4,811	10
	16	0,139	10	6,81	10
	Continuous	0,439	10	21,51	10
W_f	1	0,019 7	10	0,965 1	10
	2	0,023 6	10	1,156	10
	4	0,030 4	10	1,489	10
	8	0,041 6	10	2,038	10
	16	0,057 1	10	2,797	10
	Continuous	0,176	10	8,622	10

5.10 Overload indication

The human-vibration meter shall have an overload indicator that shall be operative for each applicable display and shall be capable of detecting overloads at all critical points in the vibration signal path. Overloading the transducer shall be avoided by appropriate means (e.g. selection of suitable transducer for the intended measurement, electrical overload detectors incorporated into the transducer, use of mechanical filter).

Overload shall be indicated before the tolerance limits for linearity or the signal-burst response tolerances are exceeded for increasing signal values above the specified upper boundary. This requirement applies for any frequency within the nominal frequency range.

The overload indicator shall operate for both positive and negative one-half-cycle signals. The difference between the positive and negative one-half-cycle signal values that just cause an overload indication shall be not more than 15 %.

When a vibration meter is used to measure time-averaged vibration values, the overload indicator shall latch on when an overload condition occurs. The latched condition shall remain on until the measurement results are reset. This requirement also applies to measurements of maximum vibration values, peak vibration values, or other quantities calculated during, or displayed after, the measurement duration.

When a vibration meter is used to measure running r.m.s. time-weighted vibration values, the overload indicator shall remain on while the overload condition exists and for any period during which the overload condition affects the displayed measurement (a period equivalent to the integration time for linear running r.m.s. acceleration values or twice the integration time for exponential averaging). Following the overload, the indicator shall remain on for at least 1 s for hand-arm vibration, 8 s for whole-body and low-frequency whole-body applications.

The instrument documentation shall describe the operation and interpretation of the overload indication and the method for clearing a latched indication.

NOTE   It is useful that the vibration meter is capable of indicating how long (in relation to the measurement duration) in each channel overload took place.

5.11 Under-range indication

If the time-weighted human vibration or time-averaged human vibration is less than the lower boundary of the linear operating range, an under-range indication shall operate before the tolerance limits on linearity are exceeded. The under-range indication shall remain on as long as the under-range condition exists or affects the displayed measurement. The minimum time for indication is 1 s for hand-arm vibration, 8 s for whole-body and low-frequency whole-body applications.

5.12 Time averaging

The instrument shall allow the measurement duration of the time-averaged weighted acceleration value to be selected or controlled by the user.

5.13 Running r.m.s. acceleration

For instruments that provide the running r.m.s. acceleration, the time constant shall be checked. A steady reference frequency sinusoidal electrical signal shall be applied to the input and then suddenly shut off. Before being shut off, the steady signal shall be applied for a period of at least 5 times the integration time for linear time averaging or for 20 times the integration time for exponential time averaging. See Annex D for details of linear and exponential running r.m.s. time averaging.

The indicated output signal value shall reduce at the rates specified in Table 10 for linear time averaging and Table 11 for exponential time averaging (if available). The decay rate shall be measured from the start of the decay to the time at which the indicated value is less than 10 % of the initial value. This requirement applies for the reference measurement range.

Table 10 — Time-weighting decay rates, linear time averaging

Time constant	Time to 10 % of original signal value
s	s
0,125	0,124 ± 0,005
1	0,99 ± 0,05
8	7,92 ± 0,2

Table 11 — Time-weighting decay rates, exponential time averaging

Time constant	Time to 10 % of original signal value	Equivalent decay rate
s	s	dB/s
0,125	0,58 ± 0,03	31 to 40
1	4,61 ± 0,25	3,8 to 4,9
8	36,8 ± 2	0,48 to 0,62

5.14 Reset

For all frequency weightings provided, instruments intended for the measurement of time-averaged human vibration, maximum transient vibration value and vibration dose value shall contain a facility to clear the data-storage device and reinitiate a measurement. The instrument documentation shall state whether the reset facility clears the overload indication. The instrument documentation also shall describe the operation of the reset facility and state the nominal delay time between the operation of a manual or remote reset facility and the initiation of a measurement.

Use of a reset facility shall not give rise to spurious indications on the display device(s).

5.15 Timing facilities

An instrument that measures time-averaged human vibration shall display the duration of the time elapsed since the start of integration. The capability to preset an integration time interval in 1 s increments may also be provided.

The tolerance limit for the indicated elapsed time is 0,1 %. The resolution of the display of elapsed time shall not be coarser than 1 s.

The instrument documentation shall state the minimum and the maximum integration times for the measurement of time-averaged vibration values for any signal value within the range of a display device.

5.16 Electrical cross-talk

Where an instrument provides simultaneous signal inputs for more than one axis (or channel) of vibration, then the response on any one channel to a signal on any of the other input channels shall be less than 0,5 % of the input signal magnitude.

This electrical cross-talk between measurement channels should be distinguished from transducer transverse sensitivity which typically is greater than 0,5 %, see Table E.1. The transverse sensitivity can become relevant especially with multi-axial transducers.

5.17 Vibration transducer characteristics

Vibration transducer characteristics shall be selected according to the measurement application, see Annex E for additional guidance.

5.18 Power supply

For battery-powered instruments, an indication shall be provided to confirm that the power supply is sufficient to operate the instrument within the specifications of this document. A check of the power supply condition shall not disturb any measurements that are underway.

When a vibration calibration signal is applied to the vibration transducer, the change in the indicated signal value shall not exceed 3 % when the supply voltage to operate the vibration instrument is reduced from the nominal value to the minimum voltage specified in the instrument documentation.

If internal batteries power the human-vibration meter, the instrument documentation shall recommend acceptable battery types and state the corresponding continuous instrument operating time, under reference environmental conditions, to be expected when full-capacity batteries are installed.

For battery-powered instruments designed to be able to measure vibration values over durations that exceed the nominal battery life, the instrument documentation shall describe suitable means for operating the instrument from an external power supply, including specifications for the acceptable voltage range and ripple content (including high-frequency spikes) of the supply.

6 Mounting

If a specific mechanical filter, mounting system or cable is required, or supplied, the instrument documentation shall state that the instrument conforms to the applicable frequency weighting specifications only when the specified devices are installed.

The mounting methods provided with the instrument, or recommended for use, shall comply with the general requirements of ISO 5348. Guidance for testing mounting systems can be found in Annex F.

The instrument documentation shall state the range of applications for which any supplied mounting system is suitable, and shall specify any circumstances in which use of the mounting system is likely to result in greater uncertainty of measurement.

7 Environmental and electromagnetic criteria

7.1 General

All specifications for the sensitivity to various operating environments apply to, and are relative to, the mechanical sensitivity under the reference environmental conditions and at the calibration check frequency. The instrument documentation shall state the typical time interval that is required for the vibration meter to stabilize after changes in environmental conditions.

One-off vibration instruments may have a restricted range of environmental application; where such a restricted range applies, this shall be stated in the instrument documentation.

NOTE   One-off vibration measurement systems are systems made up of separate signal processing, analysis (recording) and display elements, with each element of the system having been pattern evaluated, or validated, in accordance with appropriate standards or to manufacturer's specifications, see 13.1.

7.2 Air temperature

The influence of variations in air temperature on the mechanical sensitivity is specified over the range of air temperatures from –10 °C to 50 °C. The influence of variations in air temperature on the vibration sensitivity shall be no more than ± 5 % over the specified temperature ranges.

The specification for the influence of variations in air temperature applies to a complete vibration meter or to those components of a vibration meter that may be exposed routinely to large variations in air temperature.

For those components of a vibration meter designated in the instrument documentation as intended to be located in an environmentally controlled enclosure (e.g. indoors), the temperature range may be restricted to 5 °C to 30 °C. The restricted range of temperature does not apply to a complete vibration meter.

Over the ranges of air temperature specified, the linearity error at the reference frequency and the extent of the linear operating range on the reference measurement range shall remain within the tolerance limits given in 5.7.

7.3 Surface temperature

The influence of variations in measurement surface temperature on the vibration sensitivity is specified over the range of surface temperatures from −10 °C to 50 °C. The influence of variations in surface temperature on the vibration sensitivity shall be no more than ± 4 % over the specified temperature range.

The specification for the influence of variations in surface temperature applies to the accelerometer, cables and mounting systems that may come into direct contact with vibrating surfaces.

Over the range of surface temperature given in this clause, the linearity error at the reference frequency and the extent of the linear operating range on the reference measurement range shall remain within the tolerance limits given in 5.7.

7.4 Electrostatic discharge

The influence of electrostatic discharges on the operation of a vibration meter, or applicable components of a vibration meter system, shall be reduced as far as is practicable.

A vibration meter shall continue to operate as intended after exposure to a contact discharge of electrostatic voltage of up to ± 4 kV or to an air discharge of electrostatic voltage of up to ± 8 kV. The polarity of the electrostatic voltage is relative to earth ground.

Exposure to the electrostatic discharges specified in this clause shall cause no degradation of performance or loss of function in the vibration meter, except as may be specified in the instrument documentation. The instrument documentation may specify that the performance or function of a vibration meter can be degraded or lost because of electrostatic discharges. The specified degradation or loss of function shall not include any change of operating state, change of configuration, corruption or loss of any stored data, or permanently reduced operation.

7.5 Radio-frequency emissions and public-power-supply disturbances

The radio-frequency emissions from a vibration instrument shall be reduced as far as is practicable.

If the human-vibration meter allows the connection of interface or interconnection cables, the instrument documentation shall recommend typical cable lengths and shall describe the nature of all devices to which the cables may be attached.

The level of the radio-frequency electric field strength emitted by the instrument's enclosure ports shall not exceed 30 dB (relative to 1 µV/m) for frequencies from 30 MHz to 230 MHz, and shall not exceed 37 dB for frequencies above 230 MHz and up to 1 GHz. The instrument documentation shall state the operating mode(s) of the instrument, and any connecting devices, which produce the greatest emission of radio-frequency fields.

The maximum disturbance conducted to the public supply of electric power shall be within the quasi-peak and average voltage limits given in Table 12 at an AC power port. If the vibration instrument conforms to the limit on the average voltage of conducted disturbance when using a quasi-peak measuring device, the human-vibration meter shall be deemed to conform to both the quasi-peak and average voltage limits.

Table 12 — Limits for conducted disturbance to the voltage of a public supply of electric power

Frequency range MHz	Limits on voltage level of disturbance dB (re 1 μV)	
	Quasi-peak	Average
0,15 to 0,50	66 to 56	56 to 46
0,50 to 5	56	46
5 to 30	60	50
NOTE 1 See CISPR 16-1-1 for characteristics of quasi-peak measuring receivers.		
NOTE 2 The lower limits of voltage level apply at the transition frequencies.		
NOTE 3 The voltage level limits decrease linearly with the logarithm of the frequency in the range from 0,15 MHz to 0,50 MHz.		

7.6   Immunity to AC power-frequency fields and radio-frequency fields

Exposure of the complete instrument (or applicable components designated in the instrument documentation) to specified AC power-frequency and radio-frequency fields shall not cause any change in the operating state, or change of configuration, or corruption or loss of any stored data. This requirement applies for any operating mode consistent with normal operation. The instrument documentation shall state the operating mode(s) of the instrument, and any connecting devices, that have the minimum immunity (are most sensitive) to AC power-frequency and radio-frequency fields.

Immunity to AC power-frequency fields applies to exposure to a uniform r.m.s. magnetic field strength of 80 A/m at frequencies of 50 Hz and 60 Hz. The uniformity of the magnetic field strength is established before immersion of the vibration meter. The orientation of the vibration meter in the field shall be that specified in the instrument documentation for maximum sensitivity to AC power-frequency fields.

Immunity to radio-frequency fields applies over the carrier frequencies range from 26 MHz to 1 GHz, with the signal at the carrier frequency of the radio-frequency field amplitude modulated by a sinusoidal signal at the reference frequency (or frequencies) appropriate to the application of the instrument to a depth of 80 %. When unmodulated and in the absence of a vibration meter, the radio-frequency field shall have a uniform r.m.s. electric field strength of 10 V/m.

NOTE   The instrument documentation can state that the vibration meter conforms to the specifications of this document at an unmodulated r.m.s. electric field strength greater than 10 V/m.

When an AC power-frequency or radio-frequency field is applied, the change in the indicated vibration value shall not exceed ± 10 %.

For meters with an AC input power port or an AC output power port, immunity to radio-frequency common-mode interference applies over the frequency range from 0,15 MHz to 80 MHz.

For meters with signal or control ports, where any interconnecting cable between any part of the system exceeds a length of 3 m, immunity to radio-frequency common-mode interference applies over the frequency range from 0,15 MHz to 80 MHz.

7.7   Ingress of water and dust

The vibration meter shall be capable of resisting ingress of water and dust. The manufacturer shall specify the IP rating of the instrument. The instrument's IP rating shall be suited to the planned application (e.g. human-vibration exposure assessments in factories might require a rating of IP 65; measurements in laboratory conditions can only require a rating of IP 42).

NOTE   IP ratings for instrument enclosures are specified in IEC 60529.

8 Provision for use with auxiliary devices

If an optional extension cable provided by the manufacturer of the vibration meter can be placed between the accelerometer and the other components of the vibration meter, the instrument documentation shall provide details of any corrections to be applied to the results of measurements made in this manner.

The instrument documentation shall provide data on the nominal effect of optional accessories supplied by the manufacturer of the vibration meter. The data shall apply to all relevant characteristics of the vibration meter resulting from installation of the accessories. Optional accessories include accelerometer mounting devices and mechanical filters. The instrument documentation shall provide data on the typical effect on sensitivity and frequency responses.

The instrument documentation shall state whether the vibration meter conforms to the specifications required by this document when the optional accessory is installed.

If connections are provided for external filters, the instrument documentation shall describe how the connections shall be made and how the instrument is to be used to measure externally filtered vibration signals.

The instrument documentation shall provide details regarding the connection of auxiliary devices to the vibration meter and the effects, if any, of such devices on the electrical characteristics of the instrument. Auxiliary devices include printers, computers and recorders.

9 Instrument marking

An instrument that conforms to all applicable specifications of this document shall be marked, or shall display a reference to this document by number and publication date. The marking shall indicate the name or trademark of the supplier responsible for the technical specifications applicable to the complete instrument. In addition, the marking shall include the model designation and the serial number.

If the instrument consists of several separate units, each principal unit or component shall be marked as described in this clause, as practicable. All principal units comprising a complete instrument shall be identified.

10 Instrument documentation

Instrument documentation shall be supplied with each vibration meter or equivalent instrument that conforms to the specifications of this document.

If the instrument consists of several separate components, instrument documentation shall be available for the combination that forms the complete vibration meter. The instrument documentation shall describe all necessary components as well as their mutual influence.

All instrument specifications shall be given in SI units.

The instrument documentation shall contain the information specified in Annex G, where they apply to the instrument.

11 Testing and calibration

Three levels of performance testing are defined in this document.

a) Pattern evaluation or validation:

    1) pattern evaluation (targeted at manufacturers) is a full set of tests to be performed on samples of an instrument type. This test is used for product type testing or pattern approval of a production series of vibration measuring instruments. The objective of this test is to demonstrate an instrument design can meet the specifications defined in this document;

2) validation of one-off instruments (targeted at laboratory users or research users) is a limited set of tests to demonstrate that an individual vibration measuring system complies with the relevant specifications defined in this document.

b) Periodic verification (targeted at manufacturers and users) is an intermediate set of tests to be performed

— periodically (e.g. prior to, or at the time of purchase, and at least every 2 years thereafter) to verify that the performance remains within the specifications of this document, or

— following modification (e.g. use of another transducer) or repair that might affect the performance of the instrument.

c) *In situ* check (targeted at users) is a minimum level of testing, indicating that a vibration measuring instrument is likely to be functioning within the required performance specification. These tests shall be carried out immediately before and after measurements are made.

The tests are designed to assess the performance characteristics and specifications defined in Clauses 5 to 10. Table 13 shows the relationship between the specifications and associated test clauses.

Table 13 — Summary of performance characteristics and test requirements

Specification		Test type		Test clause			
Clause	Characteristic	Electrical	Mechanical	Pattern evaluation (production series)	Validation (one-off instruments)	Periodic verification	*In situ* check
5.1	General characteristics			12.5, 12.6	13.6, 13.7	14.5	15.2
5.2	Display of signal magnitude			12.5	13.6		
5.3	Electrical output	•		12.17			
5.4	Vibration sensitivity		•	12.7	13.9, 13.11	14.9	15.3
5.5	Accuracy of indication at reference frequency under reference conditions	•		12.7	13.9		
5.6	Frequency weightings and frequency responses	•	•	12.11 Annex H	13.11	14.9	
5.7	Amplitude linearity	•	•	12.10	13.11	14.9	
5.8	Instrument noise		•	12.12	13.12		
5.9	Signal-burst response	•		12.13			
5.10	Overload indication	•		12.14	13.14		
5.11	Under-range indication	•	•	12.10			
5.12	Time averaging	•		12.13			
5.13	Running r.m.s. acceleration	•		12.13			
5.14	Reset			12.15			
5.15	Timing facilities			12.18	13.15		
5.16	Electrical cross-talk	•		12.8	13.13		
5.2	Combined axis outputs	•		12.16			
5.17 (Annex E)	Vibration transducer characteristics		•	12.9			
5.18	Power supply			12.19			
6	Mounting			Annex F			
7	Environmental and electromagnetic criteria			12.20			
8	Provision for use with auxiliary devices	•		12.5,12.17			
9	Instrument marking			12.4	13.5	14.6	
10	Instrument documentation			12.4	13.5	14.6	

Compliance with the specifications of this document is achieved when there is evidence that an instrument model complies with all the requirements specified as part of the pattern evaluation as documented in accordance with Annex G, and an individual instrument of that model complies with the requirements of the periodic verification. Alternatively, compliance with the requirements of the validation of one-off instruments can be used to demonstrate compliance with the specifications of this document for an individual one-off instrument. Successful completion of any *in situ* tests does not demonstrate compliance with the specifications of this document.

12 Pattern evaluation

12.1 General

This clause provides details of the tests necessary to demonstrate conformance of a vibration instrument to all mandatory specifications of this document, along with the test methods to be used.

Conformance to a specification of this document is demonstrated when the result of a measurement of a deviation from a design goal, extended by the actual expanded uncertainty of measurement of the testing laboratory, does not exceed the specified tolerance limits.

Uncertainties of measurement shall be determined in accordance with ISO/IEC Guide 98-3. The actual expanded uncertainties shall be calculated by the testing laboratory, with a coverage factor of no less than 2.

The expanded uncertainties of measurement given in this clause are the maximum permitted for demonstration of conformance, under this clause, to the specifications of this document. Testing laboratories shall not perform tests to demonstrate conformance to the specifications of this document if their actual expanded uncertainties of measurement exceed the maximum permitted values.

No test specified in this clause shall be omitted unless the instrument does not possess the facility to be tested.

Unless otherwise specified, all tests described in this clause apply to each channel of a multi-channel instrument.

12.2 Testing requirements

Those instruments used for pattern evaluation that affect the uncertainty of test outputs shall hold valid calibrations, traceable to national standards.

The frequency of the input signals shall be within ± 0,2 % of the required value.

The value of mechanical input signals shall be within ± 2 % of the required value.

NOTE 1   Currently, the published parts of ISO 16063 do not provide for calibration below 0,4 Hz.

The environmental conditions prevailing at the time of a test shall be within the following ranges:

— air temperature: 20 °C to 26 °C;

— relative humidity: 10 % to 75 % (non-condensing).

The total distortion, d, for sinusoidal mechanical vibration test inputs shall be no greater than 5 %.

The total distortion, d, for sinusoidal electrical test inputs shall be no greater than 0,1 %.

NOTE 2   Total distortion, d, expressed as a percentage, is defined in ISO 2041 as shown by Formula (7):

$$d = \frac{\sqrt{a_{\text{tot}}^2 - a_1^2}}{a_1} \times 100 \ \% \tag{7}$$

where

a_1 is the r.m.s. acceleration at the driving frequency;

a_{tot} is the total band-limited r.m.s. acceleration (including a_1).

12.3 Submission for testing

The vibration instrument shall be submitted for testing together with its documentation and all items or accessories that are identified in the instrument documentation as integral components of the complete instrument in its configuration for normal use. Examples of additional items or accessories include an accelerometer, mounting device and cable.

The instrument shall be submitted for testing with equipment (e.g. adaptors) suitable for enabling the input and output of electrical signals.

A field vibration calibrator should be supplied with the vibration instrument.

12.4 Marking of the vibration meter and information in the instrument documentation

It shall be confirmed that the instrument is marked according to the specifications of Clause 9.

Before conducting any tests, it shall be confirmed that the instrument documentation contains all the information required by Clause 10, appropriate to the facilities provided by the vibration meter.

After completion of all tests, the information shall be reviewed to ensure that it is correct and within the appropriate tolerance limits.

12.5 Mandatory facilities and general requirements

A vibration meter shall be confirmed to conform to the requirements of 5.1.

For instruments with multiple measurement ranges, it shall be confirmed that the measurement range overlap conforms to the specifications of 5.7.

The display shall be confirmed to conform to the specifications of 5.2.

Where the instrument documentation specifies batteries of a particular model and type, such batteries shall be installed.

If the instrument does not satisfy the requirements listed in this clause, tests shall not be performed to demonstrate conformance to the performance specifications of this document.

12.6 Initial instrument preparation

Before conducting any tests, the instrument shall be given a power supply within the operating limits specified by the manufacturer. The instrument, transducer and the field vibration calibrator (if supplied) shall be visually inspected and all controls operated to ensure they are in working order.

The procedure given in the instrument documentation shall be followed to set the vibration sensitivity of the instrument at the calibration check frequency. Any adjustments required by 5.4 and given in the instrument documentation shall be applied to adjust the sensitivity of the vibration meter to display the correct vibration value under reference environmental conditions.

12.7 Indication at the reference frequency under reference conditions

The error in the indication of the reference acceleration value at the reference frequency (see Table 1) shall be determined from the difference between the vibration value displayed by the instrument and the corresponding vibration value measured by an appropriately calibrated reference vibration transducer at the same measurement point.

The error ε of the test measurement a_{test} is expressed as a percentage of the reference vibration transducer measurement a_{ref}, as shown by Formula (8):

$$\varepsilon = \frac{a_{\text{test}} - a_{\text{ref}}}{a_{\text{ref}}} \times 100 \ \%$$

(8)

NOTE   The error ε is a relative measure, i.e. a relative error expressed as percentage.

The reference vibration transducer shall be used to measure the value of the mechanical vibration input generated at the reference vibration value and reference frequency, before measuring the vibration magnitude with the vibration meter. For these measurements, the vibration meter shall be set to the reference measurement range, band-limiting frequency weighting and linear time averaging and with a measurement duration sufficient for the indicated values to stabilize (for low-frequency testing, this duration can be as much as 30 s for hand-arm vibration, 1 min for whole-body, and 5 min for low-frequency whole-body applications). The value of the input signal plus background noise shall be at least ten times the value of the background noise as measured by the vibration meter.

A minimum of three measurements of error of indication shall be obtained. For each measurement, a time interval not less than that stated in the instrument documentation for the instrument's settling time shall be allowed for the instrument to reach equilibrium with the prevailing environmental conditions before any indication is recorded. The difference between the greatest and the smallest of the three measurements shall not exceed 3 %.

The arithmetic average of the error of indication measurements shall be within the applicable tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

For each frequency weighting provided, a steady sinusoidal electrical signal shall be applied to the electrical input facility at the appropriate reference frequency. With an input signal adjusted to indicate the reference vibration value on the reference measurement range with band-limiting frequency weighting, the indicated frequency-weighted vibration values shall equal the indicated band-limited weighted vibration value multiplied by the appropriate weighting factor (see Table 1) within the tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

For an instrument where time weightings are provided, a steady sinusoidal electrical signal shall be applied to the electrical input facility at the reference frequency. The amplitude of the input signal shall be adjusted to give an indication of the reference vibration value on the reference measurement range with the vibration meter set to band-limiting frequency weighting. With the same input signal, the indicated vibration values on each time weighting shall equal the indicated reference vibration value within the tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

12.8 Electrical cross-talk

For instruments with more than one measurement channel (e.g. triaxial measurement instruments), tests shall be carried out of the electrical interference between the channels.

All channels shall be set to the reference measurement range. An electrical input shall be applied to each channel in turn at the reference frequency; the inputs to all remaining channels shall be terminated by substitute impedances. The amplitude of the test signal shall be within the upper 5 dB of the reference measurement range. The output of all channels shall be monitored during the tests.

The output from all channels shall not exceed the requirements of 5.16.

12.9 Vibration transducer

The vibration transducer characteristics (see Annex E) of the accelerometer shall be tested according to the relevant parts of ISO 5347 and ISO 16063.

12.10 Amplitude linearity and under-range indication

12.10.1 Electrical tests of amplitude linearity

The electrical tests of amplitude linearity of an instrument shall be carried out with steady sinusoidal electrical signals at the frequencies indicated in Table 14. Amplitude linearity shall be tested with the instrument set to time-averaged measurement with a band-limiting frequency weighting.

Table 14 — Amplitude linearity test frequencies and acceleration value increments

Application	Test frequencies [a] Hz	Acceleration increment dB	
		Within 5 dB of overload and under-range	At all other values
Hand-arm	8; 80; 800	1	5
Whole-body	1; 4; 16; 63	1	5
Low-frequency whole-body	0,2; 0,4	1	5
[a] Nominal centre frequencies are shown. The exact one-third-octave band centre frequencies shall be used, e.g. "8 Hz" represents the band centred on $10^{9/10}$ Hz ≈ 7,943 Hz.			

Tests of amplitude linearity shall begin with signals at the reference frequency applied to the specified electrical input facility. The input signal shall be adjusted to display the reference vibration value on the reference measurement range.

At any of the frequencies, the starting point for amplitude linearity tests on any measurement range shall be the reference vibration value multiplied by the nominal attenuation factor introduced by the measurement range control relative to the setting on the reference measurement range.

On the reference measurement range, the value of the test frequency input signal shall be increased in the increments specified in Table 14 from the specified lower boundary [see G.2 j)] of this measurement range up to the input signal value that causes the first indication of overload. The signal shall then be decreased in increments specified in Table 14 from the signal value that caused the first indication of overload down to the specified lower boundary. For each input signal value, the indication on the instrument's display device and the input signal value shall be recorded.

For each test frequency input signal value, from the specified lower boundary of the reference measurement range until the first indication of overload, amplitude linearity errors shall be within the applicable tolerance limits of 5.7. The extent of the reference frequency linear operating range on the reference measurement range shall comply with the linear operating range requirements of 5.7 between the nominal vibration magnitudes specified for the upper and lower boundaries. The maximum expanded uncertainties of measurement are 2 %.

Following tests on the reference measurement range, the amplitude linearity shall be tested on any additional measurement ranges. Tests shall be carried out at the frequencies and increments specified in Table 14 from the starting point down to the lower boundary and up to the upper boundary specified for each measurement range.

On each additional measurement range of the vibration instrument, the amplitude linearity errors shall be within the applicable tolerance limits of 5.7 over the extent of the linear operating ranges specified in the instrument documentation and until the first indications of overload. The maximum expanded uncertainties of measurement are 2 %.

For instruments that measure time-weighted vibration values and for which the linear operating range is greater than the indicator display range, amplitude linearity may be tested using tone bursts for measurements of amplitude linearity at input signals above the top of the indicator display range.

For vibration meters with time-averaging facilities for which the linear operating range is greater than the indicator display range, linearity errors above the top of the display range may be measured by using tone bursts extracted from the steady input signals. The duration of the tone bursts shall be no less than 30 s for hand-arm vibration, 5 min for whole-body vibration (this test is not practical for low-frequency whole-body vibration). Integration times shall be greater than the duration of the tone burst.

On each measurement range, and for each test frequency, the under-range indicator shall not indicate when the indicated signal value is greater than, or equal to, the specified lower boundary of the measurement range. On each measurement range and at each test frequency, the under-range indicator shall be displayed for signal values that are 1 dB less than the specified lower boundary of the range.

12.10.2 Mechanical tests of amplitude linearity

The mechanical tests of amplitude linearity of an instrument shall be carried out with steady sinusoidal mechanical signals at the frequencies indicated in Table 14. Amplitude linearity shall be tested with the instrument set to time-averaged measurement with a band-limiting frequency weighting. Amplitude linearity shall be determined as the indication on the display device minus the vibration measured by an appropriately calibrated reference vibration transducer. The vibration transducers shall be mounted in accordance with the calibration procedure specified in ISO 16063-21.

At any frequency, the starting point for amplitude linearity tests on any measurement range shall be the reference vibration value multiplied by the nominal attenuation factor introduced by the measurement range control relative to the reference measurement range.

Tests of amplitude linearity shall begin with signals at the reference frequency applied to the base of the vibration transducer. The input signal shall be adjusted to display the reference vibration value on the reference measurement range.

The mechanical amplitude linearity shall be tested over a range of no less than 40 dB.

On the reference measurement range, the value of the test frequency input signal shall be increased in the increments specified in Table 14 from the specified lower boundary of this measurement range up to the input signal value that is the lowest of

— the first indication of overload on the test instrument,

— the maximum vibration capability of the input device, or

— the maximum of the linear vibration amplitude range of the reference transducer.

The signal shall then be decreased in increments specified in Table 14 from that maximum signal value down to the input signal that is the greatest of

— the specified lower boundary of the test instrument,

— the minimum vibration amplitude capability of the input device, or

— the minimum of the linear vibration amplitude range of the reference transducer.

For each input signal value, the indication on the instrument's display device and the value measured by the reference transducer shall be recorded.

The amplitude linearity of the laboratory reference vibration transducer shall be taken into account when establishing the constant vibration value at different vibration amplitudes.

For each test frequency input signal value, from the specified lower boundary of the reference measurement range until the maximum signal value specified above, amplitude linearity errors shall be within the applicable tolerance limits of 5.7. The extent of the reference frequency linear operating range on the reference measurement range shall comply with the linear operating range requirements of 5.7 between the nominal vibration magnitudes specified for the upper and lower boundaries. The maximum expanded uncertainties of measurement are 3 %.

Following tests on the reference measurement range, the amplitude linearity shall be tested on any additional measurement ranges. Tests shall be carried out at the frequencies and increments specified in Table 14 from the starting point down to the lower boundary and up to the upper boundary specified for each measurement range.

On each additional measurement range, amplitude linearity errors shall be within the applicable tolerance limits of 5.7 over the extent of the linear operating ranges specified in the instrument documentation. The maximum expanded uncertainties of measurement are 4 %.

12.11 Frequency weightings and frequency responses

12.11.1 General

The procedure described here for assessing the frequency weighting and frequency response characteristics assumes that the vibration instrument does not have an electrical output. If an electrical output is available and used for the tests, preliminary tests shall be performed to determine the correspondence between the values of frequency-weighted vibration indicated on the display device and the voltages at the electrical output. No attempt shall be made to account for linearity errors in any test of frequency weighting.

For each application (hand-arm, whole-body and low-frequency whole-body) for which frequency weightings are provided in the vibration instrument, one frequency weighting shall be selected for testing with both sinusoidal mechanical and electrical signals. Other frequency weightings shall be tested using either mechanical or electrical signals.

Where possible, tests of frequency weightings and frequency responses shall be performed on the reference measurement range. Where the testing laboratory considers that the ability of an instrument to conform to the specifications for frequency weighting or frequency response might be influenced by the setting of the measurement range control, then additional tests shall be performed. All measurements shall be performed on measurement ranges where linearity errors are within the applicable tolerance limits given in 5.7.

The tests of frequency response shall be made in steps of not more than one-third octave across the frequency ranges specified in Table 15.

Table 15 — Test frequencies for mechanical and electrical frequency response tests

Application	Test one-third-octave-band frequency range [a] Hz	
	Electrical tests	Mechanical tests
Hand-arm	4 to 2 000	8 to 2 000
Whole-body	0,25 to 160	0,5 to 160
Low-frequency whole-body	0,05 to 1	0,4 and 0,5
[a] The range of nominal centre frequencies is shown. The exact one-third-octave band centre frequencies shall be used, e.g. "8 Hz" represents the band centred on $10^{9/10}$ Hz ≈ 7,943 Hz.		

NOTE 1   The errors, ε, mentioned in 12.11 are relative measures, i.e. relative errors expressed as percentages.

NOTE 2   For testing the magnitude frequency response, see 12.11.2 and 12.11.3. For testing the phase frequency response, see Annex H.

12.11.2 Mechanical tests of frequency response

The mechanical frequency response of the vibration instrument shall be determined by comparison with unweighted acceleration measurements made by an appropriately calibrated laboratory reference vibration transducer. The error in frequency response shall be the indication of frequency-weighted acceleration value on the vibration instrument minus the vibration value measured by the laboratory

reference vibration transducer when multiplied by the appropriate frequency weighting factor. The vibration transducers shall be mounted in accordance with the calibration procedure specified in ISO 16063-21.

At the reference frequency, the input mechanical vibration shall be adjusted such that the indication of band-limited vibration on the instrument under test is 20 dB above the lower limit of the specified linearity range. The band-limited acceleration value of this input signal, a_{in}, shall be used as a reference input value for subsequent tests.

At each test frequency, the input signal level shall be adjusted to give the same input vibration value, a_{in}, as measured by the laboratory reference vibration transducer. The value of the input vibration acceleration and the indication of the vibration meter a_{ind} shall be noted at each of the test frequencies defined in Table 15 for mechanical tests.

The frequency-response error at frequency f, $\varepsilon(f)$, expressed as a percentage, is given by Formula (9):

$$\varepsilon\left(f\right) = \frac{a_{ind}\left(f\right) - a_{in}w\left(f\right)}{a_{in}w\left(f\right)} \times 100\ \% \tag{9}$$

where $w(f)$ is the frequency weighting factor at frequency f.

The frequency response of the laboratory reference vibration transducer shall be taken into account when establishing the constant vibration value at different frequencies.

If a constant vibration value cannot be maintained over the complete range of frequencies, signal values displayed by the instrument shall be corrected, as required, for the differences between the vibration value measured by the laboratory reference vibration transducer at a test frequency and at the reference frequency.

The maximum expanded uncertainties of measurement are 4,5 % for all frequencies in the appropriate nominal frequency range.

NOTE   Where separate tests are carried out on the vibration transducer and the electrical part of the vibration instrument, then the error of the frequency weighting, ε, at frequency f is given by Formula (10):

$$\varepsilon(f) = \varepsilon_t(f) + \varepsilon_e(f) \tag{10}$$

where

    ε_t is the error of the vibration transducer response;

    ε_e is the error of the electrical part of the instrument.

In both cases, the error combines the apparent error of the measured result, ε_m, with the expanded uncertainty of measurement, u_m, as shown by Formula (11):

$$\varepsilon_t = \sqrt{\varepsilon_m^2 + u_m^2} \tag{11}$$

Annex F provides test information for mounting systems where these are provided with the instrument.

12.11.3 Electrical tests of frequency response

Sinusoidal electrical signals shall be applied to the electrical input facility of the instrument.

At the reference frequency f_{ref}, the input electrical signal shall be adjusted such that the indication of band-limited vibration on the instrument under test is 20 dB above the lower limit of the specified linearity range. The indicated frequency-weighted value, a_{ind}, of this input signal shall be used as a reference value for subsequent tests.

At each test frequency, the input r.m.s. signal value u_{in} shall be adjusted such that the same indicated frequency-weighted value, a_{ind}, is displayed. The value of the input signal and the indication of the vibration meter shall be noted at each of the test frequencies defined in Table 15 for electrical testing.

The electrical component of the frequency response error at frequency f, $\varepsilon_e(f)$, expressed as a percentage, is given by Formula (12)

$$\varepsilon_e(f) = \left[a_{ind} - \frac{u_{in}(f)}{S} w(f) \right] \Bigg/ \left[\frac{u_{in}(f)}{S} w(f) \right] \times 100 \ \% = \left[\frac{u_{in}(f_{ref}) \ w(f_{ref})}{u_{in}(f) \ w(f)} - 1 \right] \times 100 \ \% \quad (12)$$

where

$w(f)$ is the frequency weighting factor at frequency f;

S is the sensitivity, given by Formula (13):

$$S = \frac{u_{in}(f_{ref}) w(f_{ref})}{a_{ind}} \quad (13)$$

At any frequency, the r.m.s. value of the input signal plus instrument noise shall be at least ten times the r.m.s. value of the instrument noise.

If the same indicated vibration value cannot be maintained over the complete range of frequencies, signal values displayed by the instrument shall be corrected, as required, for the differences between the vibration value of the input electrical signal at a test frequency and at the reference frequency. Signal values displayed by the instrument shall also be corrected, as required, for any nonlinearity between the indication at the test frequency and the indication at the reference frequency.

The maximum expanded uncertainties of measurement are 3 % for all frequencies in the appropriate nominal frequency range.

12.11.4 Conformance

For those frequency weightings tested using the mechanical tests, the frequency weighting error is provided directly from the test i.e. $\varepsilon(f)$ in Formula (9). For frequency weightings tested only using the electrical test, the overall frequency weighting error shall account for the frequency response of the vibration transducer, $\varepsilon_t(f)$. Values for $\varepsilon_t(f)$ are obtained by subtracting the error $\varepsilon_e(f)$ from the result of the mechanical test, $\varepsilon(f)$, for the frequency weighting that has been mechanically tested, see Formula (10).

EXAMPLE   An instrument provides two whole-body weightings: W_d and W_k. W_d is selected for both mechanical and electrical frequency response testing. The response of the vibration transducer is given by the difference between the mechanical and electrical test results for W_d. This vibration transducer response is added to the electrical response for W_k to give the overall frequency response of the instrument for W_k.

For all available frequency weightings, the error of the overall frequency response of the instrument shall be within the applicable tolerance limits specified in 5.6. The maximum expanded uncertainties of measurement are 5 % for all frequencies in the appropriate nominal frequency range.

Other optional frequency responses provided shall conform to the design goals and tolerance limits stated in the instrument documentation.

12.12 Instrument noise

The typical value of instrument noise shall be determined from the arithmetic average of ten measurements with the vibration transducer of the instrument fitted to a non-vibrating object that does not add significantly to the indicated vibration value. Tests shall be carried out for both time-averaged and time-weighted vibration. For time-averaged human vibration, the averaging time shall be

stated and shall be at least 1 min for hand-arm vibration, 5 min for whole-body vibration, and 30 min for low-frequency whole-body applications.

12.13 Signal-burst response

With the instrument set to the reference measurement range and the applicable band-limiting weighting, a steady sinusoidal electrical signal at the frequency specified in Table 6 shall be applied and the signal value adjusted to obtain an indication at 50 % of the specified upper boundary of the linear operating range. The signal bursts specified in Table 6 shall then be applied to all available time and frequency weightings.

The fall time of the saw-tooth burst wave shall be no more than $1/(5\,f_2)$, where f_2 is the upper limiting frequency of the band-limiting component of the appropriate frequency weighting, defined in Table 3.

High-frequency switching transients can be produced when generating the saw-tooth wave. To avoid the test being affected by these, a single-pole low-pass filter can be necessary between the signal generator and the instrument under test. The cut-off frequency should be high enough to avoid influencing the test results, e.g. 100 f_2.

Measurements of signal-burst response shall be repeated with the value of the steady input signal reduced by factors of 10 down to an input signal value that gives an indication at least three times greater than the specified lower boundary for the linear operating range.

Measurements of single-cycle signal-burst response shall be repeated with the magnitude of the signal bursts increased until the first indication of overload.

The vibration values indicated in response to the signal bursts, relative to the values of the vibration amplitude of the input signal, shall be as specified in Table 7, 8 or 9, as appropriate for the application. The signal-burst response errors shall be within the tolerance limits given in Tables 7, 8 and 9. The maximum expanded uncertainties of measurement are 3 %.

12.14 Overload indication

Overload indications shall be tested by applying positive and negative one-half-cycle sinusoidal electrical signals at the reference frequency and the frequencies specified in Table 14. With the instrument set to the reference measurement range, band-limited frequency weighting and with a positive one-half-cycle signal, the signal value shall be increased until the first indication of overload. The process shall be repeated with a negative one-half-cycle signal. In each case, the lowest input signal value that causes the first indication of overload shall be recorded. The difference between the two input signal values at which overload is first indicated shall not exceed the tolerance limits given in 5.10. The maximum expanded uncertainties of measurement are 2 %.

NOTE   In addition to the required tests at the frequencies specified in this clause, indication of overload can be tested at other frequencies at the option of the testing laboratory.

The overload indicator shall operate for all input signal values greater than the lowest input signal value that caused an overload indication up to the maximum input signal value specified in the instrument documentation.

When time-averaged vibration values or maximum vibration values are being measured, the overload indicator shall latch on when an overload condition occurs, as specified in 5.10. Where the vibration meter is used to measure time-weighted vibration magnitudes, the overload indication shall be displayed as specified in 5.10.

12.15 Reset

Where provided, it shall be confirmed that operation of the reset facility cancels the previous display indication, and that operation of the reset facility does not give rise to spurious indications on any display device.

12.16 Combined axis outputs

This test ensures that multi-axis inputs are combined in accordance with the appropriate measurement standard when the combined axis output is displayed, e.g. root-sum-of-squares vibration total value or the total VDV.

The instrument shall be set to the reference measurement range. An electrical input signal at the reference vibration value shall be applied to each axis in turn. The indicated value for each axis shall be noted and used to calculate a combined axis result in accordance with the appropriate International Standards (ISO 2631-1, ISO 2631-2, ISO 2631-4 and ISO 5349-1). The input signal shall then be applied simultaneously to all three input channels; the indicated combined axis value shall be equal to the calculated result to within ± 3 %.

The signal on one channel shall be inverted, i.e. 180° phase change. The indicated value following the signal inversion shall not change by more than 2 %.

For whole-body vibration, the weightings used for x-, y- and z-axes and the multiplying factors, k, used for combining single-axis data, are dependent on the application, e.g. health, comfort or perception. ISO 2631-1 should be used to determine the expected outputs.

12.17 AC electrical output

An electrical signal, corresponding to the reference vibration value on the reference measurement range at the reference frequency, shall be applied to the instrument and the indication recorded. A short circuit shall then be applied to the AC electrical output and the indication of the instrument recorded. The difference between the indicated vibration values shall not exceed the tolerance limit specified in 5.3.

12.18 Timing facilities

The minimum averaging time for the measurement of time-averaged vibration values shall be verified to be no greater than the minimum averaging time specified in the instrument documentation. The maximum averaging time for the measurement of time-averaged vibration values shall be verified to be not less than the maximum averaging time specified in the instrument documentation.

A measurement shall be carried out over 2 000 s and the elapsed time shall be within ± 2 s, i.e. ± 0,1 %. The maximum expanded uncertainties of measurement are 0,01 %.

12.19 Power supply

With the field vibration calibrator supplied with the vibration meter applied to the accelerometer, the indicated vibration signal value on the reference measurement range shall be recorded with the power supply delivering the nominal voltage and then delivering the minimum voltage to the instrument as specified in the instrument documentation. The indicated signal values shall be the same within the tolerance limits of 5.18.

NOTE   The term power supply includes batteries.

12.20 Environmental, electrostatic and radio-frequency tests

12.20.1 General

A complete vibration measuring instrument shall conform to all specifications of this clause that apply to the intended use of the instrument. For conformance to the specifications of this clause, the accelerometer shall be connected to the instrument in accordance with the normal mode of operation stated in the instrument documentation.

Each specification of sensitivity to an operating environment applies to an instrument that is turned on and set to perform a measurement in a typical manner.

Before conducting, but not during, the environmental, electrostatic and radio-frequency tests, the indication at the calibration frequency shall be checked by application of the field vibration calibrator specified in 5.4 and adjusted, if necessary, to indicate the reference vibration value under reference environmental conditions. The adjustment shall use the procedure given in the instrument documentation.

The effect of environmental conditions on the magnitude produced by the field vibration calibrator, relative to the vibration value produced under reference environmental conditions, shall be accounted for in accordance with the procedure given in the instrument documentation.

Environmental conditions at the time of checking the indications shall be recorded. For environmental tests, a field vibration calibrator shall be used to provide a signal of known vibration magnitude. The vibration meter shall be set to perform a typical measurement of frequency-weighted, linear time-averaged r.m.s. vibration.

Time-averaged vibration values indicated by the vibration meter in response to the signal from the field vibration calibrator shall be recorded for each test condition.

12.20.2 Expanded uncertainties for measurements of environmental conditions

The actual expanded uncertainty of measurement shall not exceed 0,5 °C for measurements of air temperature and 10 % for measurements of relative humidity.

12.20.3 Acclimatization requirements for tests of the influence of air temperature and relative humidity

The field vibration calibrator and the vibration instrument (or relevant components) shall be placed in an environmental chamber to test the influence of air temperature and relative humidity on the vibration meter.

For tests of the influence of air temperature and relative humidity, the accelerometer shall be removed from the field vibration calibrator and the power to both instruments shall be switched off during an acclimatization period.

The field vibration calibrator and vibration instrument shall be permitted to acclimatize at the reference environmental conditions for at least 12 h.

After completion of an acclimatization period, the accelerometer shall be fitted on the field vibration calibrator and the power to both instruments shall be switched on.

12.20.4 Test of the influence of air temperature and relative humidity combined

Following the acclimatization procedures described in 12.20.3, the vibration value indicated in response to application of the field vibration calibrator shall be recorded for the following combinations of air temperature and relative humidity. For vibration instruments where all components can be operated under any combination of air temperature and relative humidity covered by the specifications of 7.2, the target test conditions are as follows:

— reference air temperature and reference relative humidity;

— air temperature of −10 °C and relative humidity of 65 %;

— air temperature of 5 °C and relative humidity of 25 %;

— air temperature of 40 °C and relative humidity of 90 %;

— air temperature of 50 °C and relative humidity of 50 %.

For each test condition, the deviation of the indicated vibration value from the vibration value indicated for reference air temperature and reference relative humidity shall be not more than that specified in 7.2.

12.20.5 Influence of surface temperature

At reference air temperature and humidity, and following acclimatization, the vibration value indicated in response to application of a vibration signal at the reference value and reference frequency shall be recorded for the following surface temperatures. The accelerometer on its specified mounting device shall be mounted directly onto a surface which can be temperature controlled to ± 5 °C. Use the following surface temperatures:

— reference temperature;

— surface temperature of –10 °C;

— surface temperature of 5 °C;

— surface temperature of 40 °C;

— surface temperature of 50 °C.

For each test condition, the deviation of the indicated vibration value from the vibration value indicated for reference air temperature and reference relative humidity shall be no more than that specified in 7.3.

12.20.6 Influence of electrostatic discharges

The equipment required to determine the influence of electrostatic discharges on the operation of a vibration instrument shall conform to the specifications given in IEC 61000-4-2:2008, Clause 6. The test set-up and test procedure shall be in accordance with the specifications given in IEC 61000-4-2:2008, Clauses 7 and 8.

Electrostatic discharge tests shall be conducted with the vibration instrument operating and set to be most susceptible to electrostatic discharge, as determined by preliminary testing. Accelerometers shall be connected to all input channels. If the instrument is fitted with connection devices that are not required for the configuration of the normal mode of operation as specified in the instrument documentation, then no cables shall be fitted during the electrostatic discharge tests. The instrument configuration at the time of testing shall be recorded.

Discharges of electrostatic voltages shall not be made to electrical connector pins that are recessed below the surface of a connector or the vibration instrument.

Electrostatic discharges of the voltages and polarities specified in 7.4 shall be applied ten times by contact and ten times through the air. Discharges shall be applied to any point on the vibration meter that is considered appropriate by the testing laboratory, see IEC 61000-4-2. The points shall be limited to those that are accessible during normal usage. If the user requires access to points inside the vibration meter, those points shall be included unless the instrument documentation prescribes precautions against damage by electrostatic discharges during this access.

Care should be taken to ensure that any effects of a discharge to the instrument under test are fully dissipated before repeating the application of a discharge.

With the vibration instrument set for the reference range, the voltage of the contact and air discharges shall be the maximum positive and the maximum negative voltage.

After a discharge, the vibration instrument shall return to the same operating state as before the discharge. Any data stored by the instrument before the discharge shall be unchanged after the discharge. Unquantified changes in the performance of the instrument are permitted when a discharge is applied.

12.20.7 Radio-frequency emissions and public-power-supply disturbances

Radio-frequency field-strength emission levels, in decibels relative to 1 µV/m, shall be measured with a quasi-peak-detector instrument for the frequency ranges specified in 7.5. Measuring receivers, antennae and test procedures shall be as specified in CISPR 22:2008, Clause 10. All emission levels shall conform

to the specifications given in 7.5. Environmental conditions prevailing at the time of the tests shall be recorded. Radio-frequency emission tests shall be conducted with the vibration meter operating, powered by its preferred supply, and set to the mode, as stated in the instrument documentation, which produces the greatest radio-frequency emissions.

All fixtures and fittings used to maintain the position of the vibration instrument shall be designed to have a negligible influence on the measurement of radio-frequency emissions from the instrument.

Initially, the radio-frequency emission levels shall be measured over the frequency ranges specified in 7.5 with the vibration meter in the reference orientation. The accelerometer, attached by the appropriate cable, shall be positioned centrally above the case of the instrument, at a height of approximately 250 mm. If the cable is longer than 250 mm, then it shall be folded back on itself, in a figure-of-eight pattern with an even number of folds of equal length and with all parts secured together at each end of the folds and in their centre.

While maintaining the accelerometer-cable-to-instrument-case arrangement specified in this clause, the radio-frequency emission levels shall be measured in at least one other plane. The other planes shall be approximately orthogonal to the principal plane of the reference orientation, within the limits of positioning for the system employed to measure radio-frequency emission levels.

If the vibration meter has any connection device that permits attachment of interface or interconnection cables, radio-frequency emission levels shall be measured with cables connected to all available connection devices. The lengths of the cables shall be as recommended in the instrument documentation. Cables shall not be terminated and shall be arranged as described in CISPR 22:2008, 8.2, unless the manufacturer of the vibration meter also supplies the device connected to the vibration meter by a cable, in which case the radio-frequency emission levels shall be measured with all items connected together.

Where several connections can be made to the same connection device, radio-frequency emission levels shall be measured with the configuration specified in the instrument documentation as producing the greatest radio-frequency emission levels. Other configurations with the same, or lower, radio-frequency emission levels may be included in the instrument documentation in a list of compliant configurations, without further testing if the tested configuration fully conforms to the limits of 7.5.

For vibration meters that are operated from a public power supply, the disturbance to the public power supply shall be measured as described in CISPR 22:2008, Clause 9, and shall conform to the specifications of 7.5 and the conducted-disturbance limits given in Table 12.

12.20.8 Immunity to AC power-frequency fields and radio-frequency fields

The instrument shall be operating while powered by the preferred supply for tests of conformance of immunity to AC power-frequency fields and radio-frequency fields.

The immunity of any vibration meter to AC power-frequency and radio-frequency fields shall be demonstrated with a vibration transducer connected to the human-vibration meter. A mechanical vibration shall be applied to the vibration transducer. The vibration shall be sinusoidal vibration at the reference frequency. With no AC power-frequency or radio-frequency field applied, the band-limited time-averaged vibration value of this test signal shall be as indicated in Table 16. The vibration value shall be indicated on the measurement range for which the lower boundary is closest to, but not greater than, the boundary shown in Table 16, if more than one measurement range is provided.

Table 16 — Immunity test values for AC power-frequency and radio-frequency fields

Application	Vibration signal value m/s^2	Maximum value of lower boundary of measurement range m/s^2
Hand-transmitted	2	1
Whole-body	0,2	0,1
Low-frequency whole-body	0,2	0,1

The vibration signal shall be applied to the accelerometer in such a manner as to cause no interference with the applied AC power-frequency or radio-frequency field. Also the method of applying the vibration signal shall not interfere with normal operation of the vibration meter, or with the instrument's susceptibility to the power-frequency or radio-frequency field.

When an AC power-frequency or radio-frequency field is applied, the change in the indicated vibration value shall not exceed ± 10 %.

For meters with an AC input power port and, if available, an AC output power port, immunity to radio-frequency common-mode interference shall be demonstrated over the frequency range from 0,15 MHz to 80 MHz. The radio-frequency field shall be 80 % amplitude-modulated by a sinusoidal signal at the reference frequency for the measurement application. When unmodulated, the r.m.s. radio-frequency voltage shall be 10 V when emitted from a 150 Ω source. Immunity to fast transients on the power supply shall apply for a signal having a 2 kV peak voltage and a repetition frequency of 5 kHz in accordance with IEC 61000-6-2:2005, Table 4. Additional specifications for immunity to voltage dips, voltage interruptions and voltage surges shall be as described in IEC 61000-6-2:2005, Table 4.

For meters with signal or control ports, where any interconnecting cable between any part of the system exceeds a length of 3 m, the specifications of IEC 61000-6-2:2005, Table 2, apply for immunity to radio-frequency common mode interference over the frequency range from 0,15 MHz to 80 MHz for a r.m.s. voltage of 10 V when unmodulated. Specifications for immunity to fast transients on the public-power-supply system shall apply for a signal having a 1 kV peak voltage and a repetition frequency of 5 kHz in accordance with IEC 61000-6-2:2005, Table 2.

In accordance with IEC 61000-4-6, for hand-held vibration meters, an artificial hand shall be placed around the instrument during tests to demonstrate immunity to common-mode, radio-frequency interference over the specified frequency range.

The instrument documentation may state that the vibration meter conforms to the specifications for exposure to AC power-frequency and radio-frequency fields at an indicated vibration that is less than that shown in Table 16. In this case, the vibration meter shall conform to the applicable tolerance limits for all vibration values less than the test value shown in Table 16 down to the stated lower value. This requirement applies to all measurement ranges for all specifications. The lower value shall be stated in the instrument documentation and shall apply to all modes of operation of the instrument.

12.21 Test report

Full details shall be given in the test report of the test configurations, test instrument orientations, test conditions and test results, including the corresponding actual expanded uncertainties of measurement. The test report shall state that the complete instrument conforms to, or does not conform to, the specifications of this document.

The additional test information noted in IEC 61000-4-3:2006, Clause 8, shall be included. Any degradation in performance, loss of function, or loss of data noted at the end of a series of electrostatic-discharge, AC power-frequency field tests or radio-frequency field tests shall be reported.

13 Validation of one-off instruments

13.1 General

A one-off vibration measurement system, also known as a "one-off instrument", is a system for measurement of vibration that is a combination of separate components (e.g. transducer, signal amplifier, A/D converter, data acquisition system, frequency analyser, software). For each component, data sheets and specifications need to be available. The whole system shall be validated according to the specifications in this clause to demonstrate its designed functionality. One-off instruments are often laboratory based, made up from general-purpose laboratory instrumentation. One-off instruments do not include prototypes of measurement systems intended for production.

Compliance with a specification of this document is demonstrated when the result of a measurement of a deviation from a design goal, extended by the actual expanded uncertainty of measurement of the testing laboratory, does not exceed the specified tolerance limits.

Uncertainties of measurement shall be determined in accordance with ISO/IEC Guide 98-3. The actual expanded uncertainties shall be calculated by the testing laboratory, with the coverage factor $k = 2$.

The validation test comprises calibration of the one-off instrument (as is generally commissioned by the end user of the one-off instrument) by a testing laboratory (calibration laboratory).

13.2 Testing requirements

Those testing instruments used for validation testing which affect the uncertainty of test outputs shall hold valid calibrations, traceable to national standards.

The frequency of the input signals shall be within ± 0,2 % of the required value.

The magnitude of mechanical input signals shall be within ± 3 % of the required value.

The total distortion for sinusoidal electrical test inputs shall be not greater than 0,1 %.

The total distortion for sinusoidal mechanical vibration test inputs shall be not greater than 5 %.

NOTE 1   For electrodynamic shakers acting below 20 Hz, the total distortion is likely to be greater than 5 %.

NOTE 2   For a mathematical definition of total distortion, see Formula (7).

The environmental conditions prevailing at the time of a test shall be within the following ranges:

— air temperature: 19 °C to 27 °C,

— relative humidity: ≤ 90 % (non-condensing).

13.3 Test object

Test object is the one-off instrument with vibration transducer(s) forming a measurement chain for the measurement and display of band-limited and frequency-weighted acceleration according to the frequency weightings W_b, W_c, W_d, W_f, W_h, W_j, W_k or W_m.

NOTE   The vibration transducer(s) can be a 3-axis (tri-axial) accelerometer or any 1-axis accelerometers.

Unless otherwise stated, all tests specified in this clause apply to each channel of a multi-channel one-off instrument.

Where a component documentation specifies batteries of a particular model and type, such batteries shall be installed.

13.4 Submission for testing

A vibration transducer of a type intended for use with the one-off instrument shall be supplied with the instrument.

Vibration transducers other than that provided for testing may be used with the one-off instrument, provided that the specification of those other vibration transducers is similar to that supplied for testing.

The one-off instrument shall be submitted for testing with equipment (e.g. adaptors) suitable for enabling the input and output of electrical signals.

A field vibration calibrator should be supplied with the one-off instrument.

13.5 Marking of the one-off instrument and information in the instrument documentation

It shall be confirmed that the one-off instrument is marked according to the specifications of Clause 9.

Before conducting any tests, it shall be confirmed that the one-off instrument documentation contains all the information required by Clause 10, appropriate to the facilities provided by the one-off instrument.

After completion of all tests, the information shall be reviewed to ensure that it is correct and within the appropriate tolerance limits.

13.6 Mandatory facilities and general requirements

The one-off instrument shall be confirmed to conform to the requirements of 5.1.

For one-off instruments with multiple measurement ranges, it shall be confirmed that the measurement range overlap conforms to the specifications of 5.7.

The display shall be confirmed to conform to the specifications of 5.2.

13.7 Initial instrument preparation

The one-off instrument, transducer and the field vibration calibrator (if supplied) shall be visually inspected and all controls operated to ensure they are in working order.

The procedure given in the one-off instrument documentation shall be followed to set the vibration sensitivity of the one-off instrument at the calibration check frequency. Any adjustments required by 5.4 and given in the one-off instrument documentation shall be applied to adjust the sensitivity of the one-off instrument to display the correct vibration value under reference environmental conditions.

13.8 Test procedure

For the following three typical applications, test procedures and parameters are specified which comprise only those tests of the one-off instrument which are relevant to the application concerned:

a) vibration measurement chain for hand-arm vibration;

b) vibration measurement chain for whole-body vibration;

c) vibration measurement chain for low-frequency whole-body vibration.

NOTE   At present, no validation test is specified for one-off instruments measuring rotational whole-body vibration.

These test procedures comprise the mechanical test of the combination of accelerometer and instrument, constituting a measurement chain which is set to the appropriate weighting filter(s). The validity of the

validation test as stated on the calibration certificate is therefore limited to the application for which testing was performed.

Where necessary, the end user can also commission testing of system configurations which differ from the typical configurations. The objective in all cases, however, is a calibration and test only of the measurement chain configuration which is actually used by the end user.

Each test procedure comprises mechanical calibration of the measurement chain with sinusoidal signals of defined amplitude and frequency. These test parameters are specified in 13.10. From the measurement results, the following is derived:

— vibration sensitivity of the measurement chain;

— the amplitude linearity (or any deviation) at discrete input values;

— the frequency response at discrete frequencies;

— instrument noise.

Additional electrical tests yield results for the following characteristics:

— electrical cross talk;

— overload;

— timing facilities.

13.9 Indication at the reference frequency under reference conditions

The error in the indication of the reference acceleration value at the reference frequency (see Table 1) shall be determined from the difference between the vibration value displayed by the one-off instrument and the corresponding vibration value measured by an appropriately calibrated reference vibration transducer at the same measurement point.

The error ε of the test measurement a_{test} is expressed as a percentage of the reference vibration transducer measurement a_{ref}, as shown by Formula (14):

$$\varepsilon = \frac{a_{\text{test}} - a_{\text{ref}}}{a_{\text{ref}}} \times 100 \ \%$$

(14)

NOTE   The error ε is a relative measure, i.e. a relative error expressed as percentage.

The reference vibration transducer shall be used to measure the value of the mechanical vibration input generated at the reference vibration value and reference frequency, before measuring the vibration magnitude with the one-off instrument. For these measurements, the one-off instrument shall be set to the reference measurement range, band-limiting frequency weighting and linear time averaging and with a measurement duration sufficient for the indicated values to stabilize (for low-frequency testing, this duration can be as much as 30 s for hand-arm vibration, 1 min for whole-body, and 5 min for low-frequency whole-body applications). The value of the input signal plus background noise shall be at least ten times the value of the background noise as measured by the one-off instrument.

A minimum of three measurements of error of indication shall be obtained. For each measurement, a time interval not less than that stated in the one-off instrument documentation for the instrument's settling time shall be allowed for the one-off instrument to reach equilibrium with the prevailing environmental conditions before any indication is recorded. The difference between the greatest and the smallest of the three measurements shall not exceed 3 %.

The arithmetic average of the error of indication measurements shall be within the applicable tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

For each frequency weighting provided, a steady sinusoidal electrical signal shall be applied to the electrical input facility at the appropriate reference frequency. With an input signal adjusted to indicate the reference vibration value on the reference measurement range with band-limiting frequency weighting, the indicated frequency-weighted vibration values shall equal the indicated band-limited weighted vibration value multiplied by the appropriate weighting factor (see Table 1) within the tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

For a one-off instrument where time weightings are provided, a steady sinusoidal electrical signal shall be applied to the electrical input facility at the reference frequency. The amplitude of the input signal shall be adjusted to give an indication of the reference vibration value on the reference measurement range with the one-off instrument set to band-limiting frequency weighting. With the same input signal, the indicated vibration values on each time weighting shall equal the indicated reference vibration value within the tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

13.10 Test parameters

13.10.1 Vibration measurement chain for hand-arm vibration

Frequency weighting:	W_h
Reference frequency:	79,58 Hz
Reference acceleration:	10,0 m/s^2
Range of unweighted input r.m.s. values for mechanical amplitude linearity test:	5 m/s^2 to 100 m/s^2 at 79,58 Hz
Unweighted input r.m.s. values:	(5; 7,5; 10; 25; 50; 75; 100) m/s^2
Frequency range for frequency response:	5 Hz to 1 000 Hz at 10,0 m/s^2
Exact frequencies:	(5,012; 6,310; 7,943; 10; 15,85; 31,62; 63,10; 79,43; 125,9; 251,2; 501,2; 794,3; 1 000) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur.

13.10.2 Vibration measurement chain for whole-body vibration

Frequency weightings:	$W_b, W_c, W_d, W_j, W_k, W_m$
Reference frequency:	15,915 Hz
Reference acceleration:	1,00 m/s^2
Range of unweighted input r.m.s. values for mechanical amplitude linearity test:	0,1 m/s^2 to 50 m/s^2 at 15,915 Hz
Unweighted input r.m.s. values:	(0,1; 0,25; 0,5; 0,75; 1; 2,5; 5; 7,5; 10; 25; 50) m/s^2
Frequency range for frequency response:	0,63 Hz to 125 Hz at 1,00 m/s^2
Exact frequencies:	(0,631; 1; 1,259; 1,995; 3,981; 7,943; 15,85; 31,62; 63,10; 79,43; 125,9) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur.

13.10.3 Vibration measurement chain low-frequency whole-body vibration

Frequency weighting:	W_f
Reference frequency:	0,397 9 Hz
Reference acceleration:	0,1 m/s^2
Range of unweighted input r.m.s. values for mechanical amplitude linearity test:	0,01 m/s^2 to 1 m/s^2 at 0,397 9 Hz
Unweighted input r.m.s. values:	(0,01; 0,025; 0,05; 0,075; 0,1; 0,25; 0,5; 0,75; 1) m/s^2
Frequency range for frequency response:	0,1 Hz to 0,5 Hz at 0,1 m/s^2
Exact frequencies:	(0,1; 0,125 9; 0,199 5; 0,398 1; 0,501 2) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur. Some combinations of frequency and amplitude might exceed the displacement capability of the shaker, which is to be documented in the test report.

13.11 Conducting the test

Before conducting any tests, the one-off instrument shall be given a power supply within the operating limits specified by the component manufacturer(s).

The complete mechanical tests are performed by three separate tests:

— adjustment of vibration sensitivity at the reference frequency and reference acceleration;

— measurement of amplitude linearity response at the reference frequency;

— measurement of frequency response with a constant input vibration magnitude (within the limits of the testing equipment).

The transducer shall be connected in the best way to the mounting surface of the shaker. Care shall be taken to avoid that the fixing attachment affects the frequency response at high frequencies.

A system for calibration by comparison in accordance with ISO 16063-21 should be used. The system shall be capable to adjust the defined amplitudes which shall be constant over the measurement time.

The measurements shall be performed using the complete one-off instrument which usually consists of a transducer (accelerometer), cable, A/D converter and acquisition system.

For the weighting filter selected, the vibration sensitivity of the one-off instrument at the reference frequency and reference acceleration shall be determined in each channel and then adjusted.

For the measurement of amplitude linearity response at the reference frequency within one measurement range, the amplitudes given in 13.10 shall be used. The values a_n at the display shall be documented. The linearity error which is the deviation, in %, at the values a_n minus the deviation at the reference acceleration a_{ref} shall be within the limits given in 5.7. The maximum expanded uncertainties of measurement are 4 %.

For the measurement of frequency response with a nearly constant input vibration magnitude, the frequencies given in 13.10 shall be used. The values a_n at the display shall be documented. The deviation from the design goals (see Annex B) shall be within the tolerances given in Table 5. The maximum expanded uncertainties of measurement are 4 %.

13.12 Instrument noise

The typical value of instrument noise shall be determined from the arithmetic average of ten measurements with the vibration transducer of the one-off instrument fitted to a non-vibrating object that does not add significantly to the indicated vibration value. Tests shall be carried out for both time-averaged and time-weighted vibration.

For time-averaged human vibration, the averaging time shall be stated and shall be at least 1 min for hand-arm vibration, 5 min for whole-body vibration, and 30 min for low-frequency whole-body applications.

13.13 Electrical cross-talk

For one-off instruments with more than one measurement channel (e.g. triaxial measuring instruments), tests shall be carried out of the electrical interference between the channels.

All channels shall be set to the reference measurement range. An electrical input shall be applied to each channel in turn at the reference frequency; the inputs to all remaining channels shall be terminated by substitute impedances. The amplitude of the test signal shall be within the upper 5 dB of the reference measurement range. The output of all channels shall be monitored during the tests.

The output from all channels shall not exceed the requirements of 5.16.

13.14 Overload indication

Overload indications shall be tested by applying positive and negative one-half-cycle sinusoidal electrical signals at the reference frequency and the frequencies specified in Table 14. With the one-off instrument set to the reference measurement range, band-limited frequency weighting and with a positive one-half-cycle signal, the signal value shall be increased until the first indication of overload. The process shall be repeated with a negative one-half-cycle signal. In each case, the lowest input signal value that causes the first indication of overload shall be recorded. The difference between the two input signal values at which overload is first indicated shall not exceed the tolerance limits given in 5.10. The maximum expanded uncertainties of measurement are 2 %.

NOTE   In addition to the required tests at the frequencies specified in this clause, indication of overload can be tested at other frequencies at the option of the testing laboratory.

The overload indicator shall operate for all input signal values greater than the lowest input signal value that caused an overload indication up to the maximum input signal value specified in the one-off instrument documentation.

When time-averaged vibration values or maximum vibration values are being measured, the overload indicator shall latch on when an overload condition occurs, as specified in 5.10. Where the one-off instrument is used to measure time-weighted vibration magnitudes, the overload indication shall be displayed as specified in 5.10.

13.15 Timing facilities

The minimum averaging time for the measurement of time-averaged vibration values shall be verified to be no greater than the minimum averaging time specified in the one-off instrument documentation. The maximum averaging time for the measurement of time-averaged vibration values shall be verified to be not less than the maximum averaging time specified in the one-off instrument documentation.

A measurement shall be carried out over 2 000 s and the elapsed time shall be within ± 2 s, i.e. ± 0,1 %. The maximum expanded uncertainties of measurement are 0,01 %.

13.16 Test report

Full details shall be given in the test report of the test configurations, test conditions and test results. The test report shall state that the complete one-off instrument has been validated, or has not been validated, as conforming to the specifications of this document as far as has been tested.

14 Periodic verification

14.1 General

Compliance with a specification of this document is demonstrated when the result of a measurement of a deviation from a design goal, extended by the actual expanded uncertainty of measurement of the testing laboratory, does not exceed the specified tolerance limits.

Uncertainties of measurement shall be determined in accordance with ISO/IEC Guide 98-3. The actual expanded uncertainties shall be calculated by the testing laboratory, with the coverage factor $k = 2$.

The verification test comprises calibration of the vibration measuring instrumentation (as is generally commissioned by the end user of the instrument) by a testing laboratory (calibration laboratory). The verification test shall be conducted regularly.

14.2 Testing requirements

The testing instruments used for verification tests which affect the uncertainty of test outputs shall hold valid calibrations, traceable to national standards.

The frequency of the input signals shall be within ± 0,2 % of the required value.

The magnitude of mechanical input signals shall be within ± 3 % of the required value.

The total distortion for sinusoidal mechanical vibration test inputs shall be not greater than 5 %.

NOTE 1   For electrodynamic shakers acting below 20 Hz, the total distortion is likely to be greater than 5 %.

NOTE 2   For a mathematical definition of total distortion, see Formula (7).

The environmental conditions prevailing at the time of a test shall be within the following ranges:

— air temperature: 19 °C to 27 °C;

— relative humidity: ≤ 90 % (non-condensing).

14.3 Test object

Test object is the vibration meter with vibration transducer(s) forming a measurement chain for the measurement and display of band-limited and frequency-weighted acceleration according to the frequency weightings W_b, W_c, W_d, W_f, W_h, W_j, W_k or W_m.

NOTE   The vibration transducer(s) can be a 3-axis (tri-axial) accelerometer or any 1-axis accelerometers.

Unless otherwise stated, all tests specified in this clause apply to each channel of a multi-channel instrument.

Where the instrument documentation specifies batteries of a particular model and type, such batteries shall be installed.

14.4 Submission for testing

A vibration transducer of a type recommended for use with the vibration instrument shall be supplied with the vibration meter.

Vibration transducers other than that provided for verification testing may be used with the vibration instrument, provided that the specification of those other vibration transducers are similar to that supplied for testing.

A field vibration calibrator can be supplied with the vibration instrument.

14.5 Preliminary inspection

The instrument, transducer and the field vibration calibrator (if supplied) shall be visually inspected. This inspection shall include inspections of the following:

— the transducer, cable and instrument case: these shall show no visible signs of physical damage;

— the connections between the transducer, cable and instrument and any other connections between components of the vibration instrument: these shall be secure.

All controls shall be operated to ensure they are in working order.

14.6 Marking of the vibration meter and information in the instrument documentation

It shall be confirmed that the instrument is marked according to the specifications of Clause 9.

Before conducting any tests, it shall be confirmed that the instrument documentation contains all the information required by Clause 10, appropriate to the facilities provided by the vibration meter.

After completion of all tests, the information shall be reviewed to ensure that it is correct and within the appropriate tolerance limits.

14.7 Test procedure

For the following three typical applications, test procedures and parameters are specified which comprise only those tests of the vibration measuring instrument which are relevant to the application concerned:

a) vibration measurement chain for hand-arm vibration;

b) vibration measurement chain for whole-body vibration;

c) vibration measurement chain for low-frequency whole-body vibration.

NOTE   At present, no verification test is specified for vibration meters measuring rotational whole-body vibration.

Each test procedure comprises the mechanical test of the combination of transducer and instrument, constituting a measurement chain which is set to the appropriate weighting filter(s). The validity of the verification test as stated on the calibration certificate is therefore limited to the application for which testing was performed.

Where necessary, the end user can also commission testing of system configurations which differ from the typical configurations. The objective in all cases, however, is a calibration and test only of the measurement chain configuration which is actually used by the end user.

The test procedure comprises mechanical calibration of the measurement chain with sinusoidal signals of defined amplitude and frequency. These test parameters are specified in 14.8. From the measurement results, the following is derived:

— the vibration sensitivity of the measurement chain;

— the amplitude linearity (or any deviation) at discrete input values;

— the frequency response at discrete frequencies.

14.8 Test parameters

14.8.1 Vibration measurement chain for hand-arm vibration

Frequency weighting:	W_h
Reference frequency:	79,58 Hz
Reference acceleration:	10,0 m/s^2
Unweighted input r.m.s. values for mechanical amplitude linearity test:	5 m/s^2, 10,0 m/s^2, 100 m/s^2 at 79,58 Hz
Frequency range for frequency response:	10 Hz to 800 Hz at 10,0 m/s^2
Exact frequencies:	(10; 15,85; 79,43; 158,5; 794,3) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur.

14.8.2 Vibration measurement chain for whole-body vibration

Frequency weightings:	W_b, W_c, W_d, W_j, W_k, W_m
Reference frequency:	15,915 Hz
Reference acceleration:	1,00 m/s^2
Unweighted input r.m.s. values for mechanical amplitude linearity test:	0,1 m/s^2, 1,00 m/s^2, 10 m/s^2 at 15,915 Hz
Frequency range for frequency response:	2 Hz to 63 Hz at 1,00 m/s^2
Exact frequencies:	(1,995; 7,943; 15,85; 63,10) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur.

NOTE   The frequencies given lie in that frequency range of the weighting curves where the tolerance band is ± 1 dB (see Annex B). For those weighting curves where the tolerance band of ± 1 dB extends to lower frequencies than 2 Hz it is desirable to extend the frequency range below 2 Hz down to those frequencies where the tolerance band still is ± 1 dB.

14.8.3 Vibration measurement chain low-frequency whole-body vibration

Frequency weighting:	W_f
Reference frequency:	0,397 9 Hz
Reference acceleration:	0,1 m/s^2
Unweighted input r.m.s. values for mechanical amplitude linearity test:	0,01 m/s^2, 0,1 m/s^2, 1 m/s^2 at 0,397 9 Hz
Frequency range for frequency response:	0,2 Hz to 0,4 Hz at 0,1 m/s^2
Exact frequencies:	(0,199 5; 0,251 2; 0,397 9) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur. Some combinations of frequency and amplitude might exceed the displacement capability of the shaker, which is to be documented in the test report.

14.9 Conducting the test

Before conducting any tests, the instrument shall be given a power supply within the operating limits specified by the manufacturer.

The complete mechanical tests are performed by three separate tests:

— adjustment of vibration sensitivity at the reference frequency and reference acceleration;

— measurement of amplitude linearity response at the reference frequency;

— measurement of frequency response with a constant input vibration magnitude.

The transducer shall be connected in the best way to the mounting surface of the shaker. Care shall be taken to avoid that the fixing attachment affects the frequency response at high frequencies.

A system for calibration by comparison in accordance with ISO 16063-21 should be used. The system shall be capable to adjust the defined amplitudes which shall be constant over the measurement time.

The measurements shall be performed using the complete measurement chain.

For the weighting filter selected, the vibration sensitivity of the vibration meter at the reference frequency and reference acceleration shall be determined in each channel and then adjusted.

For the measurement of amplitude linearity response at the reference frequency within one measurement range, the amplitudes given in 14.8 shall be used. The values a_n at the display shall be documented. The linearity error which is the deviation, in %, at the values a_n minus the deviation at the reference acceleration a_{ref} shall be within the limits given in 5.7. The maximum expanded uncertainties of measurement are 5 %.

For the measurement of frequency response with a nearly constant input vibration magnitude, the frequencies given in 14.8 shall be used. The values a_n at the display shall be documented. The deviation from the design goals (see Annex B) shall be within the tolerances given in Table 5. The maximum expanded uncertainties of measurement are 5 %.

14.10 Test report

Full details shall be given in the test report of the test configurations, test conditions and test results. The test report shall state that the complete instrument has been verified, or has not been verified, as conforming to the specifications of this document as far as has been tested.

15 *In situ* checks

15.1 General

In situ checks are intended for application in the field prior to and following a measurement or series of measurements. They act as a check of the instrument's basic calibration and functionality.

The instrument documentation shall include instructions for routine *in situ* checks.

15.2 Preliminary inspection

The instrument documentation shall specify a visual inspection to confirm the physical integrity of the instrument. This inspection shall include inspections of the following:

— the accelerometer, cable and instrument case: these shall show no visible signs of physical damage;

— the connections between the accelerometer, cable and instrument and any other connections between components of the vibration instrument: these shall be secure.

15.3 Vibration sensitivity (field calibration)

The instrument documentation shall define an *in situ* check of vibration sensitivity. This shall include the following.

— A procedure for checking the mechanical vibration sensitivity of the vibration measuring instrument, to be carried out at the reference vibration value on the reference measurement range and at the calibration check frequency using the specified field vibration calibrator.

For hand-arm vibration *in situ* checks only, a check frequency of 159,15 Hz is permissible; the expected indication value can be derived from Table B.6.

NOTE   If, according to gained experience, it can be assumed that the sensitivity of transducer and instrument do not alter, a quantitative determination of the overall sensitivity of the vibration meter can be omitted. In this case, however, a mechanical overall tapping test is mandatory to demonstrate that the signal path is uninterrupted.

— An indication of the maximum change in vibration sensitivity likely to occur in normal use (i.e. the expected range of adjustment to vibration sensitivity; adjustments greater than this range can be an indication of instrument faults).

— A recommended procedure for recording field calibration results; this shall include details of the date and time of test, settings of the vibration meter and field vibration calibrator, the initial sensitivity and adjustments made to the sensitivity.

Annex A
(normative)

Specification for field vibration calibrator

A.1 General

A field vibration calibrator (mechanical calibrator) serves to generate a mechanical vibration with specified characteristics. This vibration is applied to the vibration transducer for *in situ* checks of vibration sensitivity.

The field vibration calibrator shall have a flat coupling surface (vibration table) to which the vibration transducer is mounted.

A.2 Specification

A field vibration calibrator shall satisfy the following requirements:

Direction of vibration vector:	normal with respect to the coupling surface.
Cross-axis/transverse vibration:	< 10 % within a specified range of payload.
Spatial orientation:	arbitrary.
Warm-up time:	the time between switching on and compliance with the manufacturer's specifications and the requirements specified in this document shall be < 10 s.
Frequency:	the calibrator shall operate at one or more of the frequencies given in Table A.1. Other frequencies may also be provided.
Vibration magnitude:	see Table A.1. Other vibration magnitudes may also be provided.
Load capacity, permissible mass:	sufficient for the vibration transducer in question (including coupling devices, if appropriate) but no less than 70 g which is the mass required for a verification using a standard vibration transducer. The minimum and maximum load capacity shall be indicated in the instrumentation documentation.
Total distortion:	< 5 % within the specified range of load capacity.
Surface flatness:	nominally flat, such that measurements are not affected by base strain, within the allowed tolerances for distortion.
(Tapped) mounting hole:	90° ± 1°
Magnetic scatter field (alternating) close to the vibration transducer in any direction:	< 1 mT
Electromagnetic compatibility:	test level 2 as specified in IEC 61000-4-3:2006.

| Degree of protection against dust and splash water: | dependent on application, shall be specified in instrument documentation. |

Temperature range: 0 °C to 40 °C

Range of relative humidity: 10 % to 90 % not condensing.

The technical data supplied with the field vibration calibrator (e.g. in the form of a calibration certificate or in the instrumentation documentation) shall list the expected readings as weighted acceleration (all possible modes of a vibration meter) for all combinations of selectable frequencies and vibration magnitudes of the calibrator.

Table A.1 — Preferred values and limits of error for the field vibration calibrator

Characteristic	Measurement type			
	Hand-arm		Whole-body	Low-frequency whole-body
Frequency	500 rad/s ± 0,5 % (79,58 Hz)	1 000 rad/s ± 0,5 % (159,15 Hz)	100 rad/s ± 0,5 % (15,915 Hz)	2,5 rad/s ± 0,5 %[a] (0,397 9 Hz)
Root-mean-square (r.m.s.) acceleration	10 m/s^2 ± 3 %	10 m/s^2 ± 3 %	1 m/s^2 ± 3 %	0,1 m/s^2 ± 5 %
[a] It is recognized that field vibration calibrators are not currently available at such low frequencies, and that vibration transducer calibration standards do not currently provide calibration methods validated at this frequency. However, to perform reliable measurement of low-frequency whole-body vibration it is desirable to perform calibration checks at a frequency within the frequency range of the measurement. The alternative is either to perform checks at static acceleration (i.e. transducer inversion providing a 2 g_n change in acceleration) or to test at frequencies much higher than the measurement range: neither of these options is ideal.				

A.3 Pattern evaluation and verification test

Pattern evaluation and verification of the field vibration calibrator shall be demonstrated by tests based upon a comparison with a reference vibration transducer, within the scope of ISO 16063-21, covering portable calibrators intended for field use.

The test method uses comparison with a reference transducer mounted directly to the coupling surface of the field vibration calibrator. The procedure is to measure the r.m.s. acceleration and frequency produced by the calibrator. The field vibration calibrator shall be confirmed to produce a vibration signal at the frequency and amplitude given in Table A.1 for the relevant application. The expanded uncertainties of measurement shall be calculated in accordance with of ISO 16063-21:2003, Annex A.

Annex B
(informative)

Frequency weightings

The values for the frequency weightings and tolerances given in Tables B.1 to B.9, and shown in Figures B.1 to B.18 as an informative illustration, were calculated from the design goals defined by Tables 3 to 5, and Formulae (1) to (5).

The frequency-weighting values given in the tables are based on true one-third-octave centre frequencies, f_c, given by Formula (B.1):

$$f_c\left(n\right) = 10^{n/10}\ \text{Hz} \tag{B.1}$$

where n is the frequency band number according to IEC 61260-1.

The centre frequencies are as defined in IEC 61260-1 using base-10 filter calculation of the one-third-octave centre frequency.

The nominal centre frequencies given are often used to describe individual bands but, when applying frequency weighting factors to one-third-octave-band data, the weighting factors for the actual centre frequencies should always be used.

NOTE 1   Some measurement standards have tabulated frequency weightings based on the nominal centre frequencies. In this document, however, the frequency weightings are based on the actual centre frequencies; this can result in some weighting factors being different from those in measurement standards.

The weighting filters tabulated in this annex are the overall frequency weightings [defined by Formula (5)], i.e. the tabulated weightings include band limiting. The tolerances given apply to both band-limiting and weighting filters.

NOTE 2   For information in this annex, the values of weighting factors, phases and exact centre frequencies are presented to four significant figures and the decibel weighting levels are presented to two decimal places. The precision of these tabulated values does not indicate the accuracy required in instrumentation.

NOTE 3   Due to their different definitions, the one-third-octave mid-band frequencies used in Tables B.1 to B.9 for presentation of the weighting curves do not exactly coincide with the calibration reference frequencies according to Table 1.

NOTE 4   At those one-third-octave mid-band frequencies where in the graphical representations the tolerance changes, that tolerance value applies that is given in the corresponding table.

Table B.1 — Frequency weighting W_b for vertical whole-body vibration, z-axis, seated, standing or recumbent person, based on ISO 2631-4

n	Frequency Hz Nomi-nal	True	Band-limiting Factor	dB	Phase degrees	Weighting W_b Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ degrees
−10	0,1	0,1	0,062 38	−24,10	159,3	0,024 94	−32,06	160	+26/−100	+2/−∞	+∞/−∞
−9	0,125	0,125 9	0,098 57	−20,12	153,6	0,039 41	−28,09	154,5	+26/−100	+2/−∞	+∞/−∞
−8	0,16	0,158 5	0,155 1	−16,19	146,3	0,061 98	−24,15	147,4	+26/−100	+2/−∞	+∞/−∞
−7	0,2	0,199 5	0,241 5	−12,34	136,6	0,096 45	−20,31	138,1	+26/−100	+2/−∞	+∞/−∞
−6	0,25	0,251 2	0,366 9	−8,71	124,1	0,146 4	−16,69	126	+26/−100	+2/−∞	+∞/−∞
−5	0,315	0,316 2	0,53	−5,51	108,3	0,211 3	−13,50	110,7	+26/−21	+2/−2	+12/−12
−4	0,4	0,398 1	0,703 7	−3,05	90,06	0,28	−11,06	93,14	+26/−21	+2/−2	+12/−12
−3	0,5	0,501 2	0,843 4	−1,48	71,76	0,334 7	−9,51	75,73	+26/−21	+2/−2	+12/−12
−2	0,63	0,631	0,927 9	−0,65	55,78	0,366 6	−8,72	60,94	+12/−11	+1/−1	+6/−6
−1	0,8	0,794 3	0,969 3	−0,27	43,01	0,380 8	−8,39	49,84	+12/−11	+1/−1	+6/−6
0	1	1	0,987 4	−0,11	33,15	0,385 3	−8,29	42,42	+12/−11	+1/−1	+6/−6
1	1,25	1,259	0,994 9	−0,04	25,54	0,386 4	−8,26	38,51	+12/−11	+1/−1	+6/−6
2	1,6	1,585	0,998	−0,02	19,58	0,391 6	−8,14	38,27	+12/−11	+1/−1	+6/−6
3	2	1,995	0,999 2	−0,01	14,84	0,416 8	−7,60	41,76	+12/−11	+1/−1	+6/−6
4	2,5	2,512	0,999 7	0,00	10,97	0,496	−6,09	46,57	+12/−11	+1/−1	+6/−6
5	3,15	3,162	0,999 9	0,00	7,74	0,665 3	−3,54	45,79	+12/−11	+1/−1	+6/−6
6	4	3,981	0,999 9	0,00	4,941	0,885	−1,06	34,64	+12/−11	+1/−1	+6/−6
7	5	5,012	1	0,00	2,416	1,026	0,22	17,75	+12/−11	+1/−1	+6/−6
8	6,3	6,31	1	0,00	0,024 4	1,054	0,46	1,77	+12/−11	+1/−1	+6/−6
9	8	7,943	1	0,00	−2,366	1,026	0,23	−11,94	+12/−11	+1/−1	+6/−6
10	10	10	0,999 9	0,00	−4,887	0,974 5	−0,22	−24,56	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,999 9	0,00	−7,679	0,904 2	−0,87	−37,1	+12/−11	+1/−1	+6/−6
12	16	15,85	0,999 7	0,00	−10,9	0,814 4	−1,78	−49,93	+12/−11	+1/−1	+6/−6
13	20	19,95	0,999 2	−0,01	−14,75	0,708 8	−2,99	−62,89	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	−19,47	0,597 3	−4,48	−75,75	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,995	−0,04	−25,4	0,490 6	−6,18	−88,55	+12/−11	+1/−1	+6/−6
16	40	39,81	0,987 7	−0,11	−32,97	0,395	−8,07	−101,7	+12/−11	+1/−1	+6/−6
17	50	50,12	0,969 9	−0,27	−42,78	0,311 8	−10,12	−116	+12/−11	+1/−1	+6/−6
18	63	63,1	0,929 1	−0,64	−55,49	0,238 9	−12,44	−132,2	+12/−11	+1/−1	+6/−6
19	80	79,43	0,845 7	−1,46	−71,41	0,173 4	−15,22	−150,9	+26/−21	+2/−2	+12/−12
20	100	100	0,707 1	−3,01	−89,68	0,115 4	−18,75	−171,3	+26/−21	+2/−2	+12/−12
21	125	125,9	0,533 6	−5,46	−107,9	0,069 29	−23,19	−191,3	+26/−21	+2/−2	+12/−12
22	160	158,5	0,369 9	−8,64	−123,8	0,038 18	−28,36	−208,5	+26/−100	+2/−∞	+∞/−∞
23	200	199,5	0,243 6	−12,27	−136,4	0,019 99	−33,98	−222,2	+26/−100	+2/−∞	+∞/−∞
24	250	251,2	0,156 5	−16,11	−146,1	0,010 2	−39,82	−232,8	+26/−100	+2/−∞	+∞/−∞
25	315	316,2	0,099 5	−20,04	−153,5	0,005 154	−45,76	−240,8	+26/−100	+2/−∞	+∞/−∞
26	400	398,1	0,062 97	−24,02	−159,2	0,002 591	−51,73	−247,1	+26/−100	+2/−∞	+∞/−∞

Key
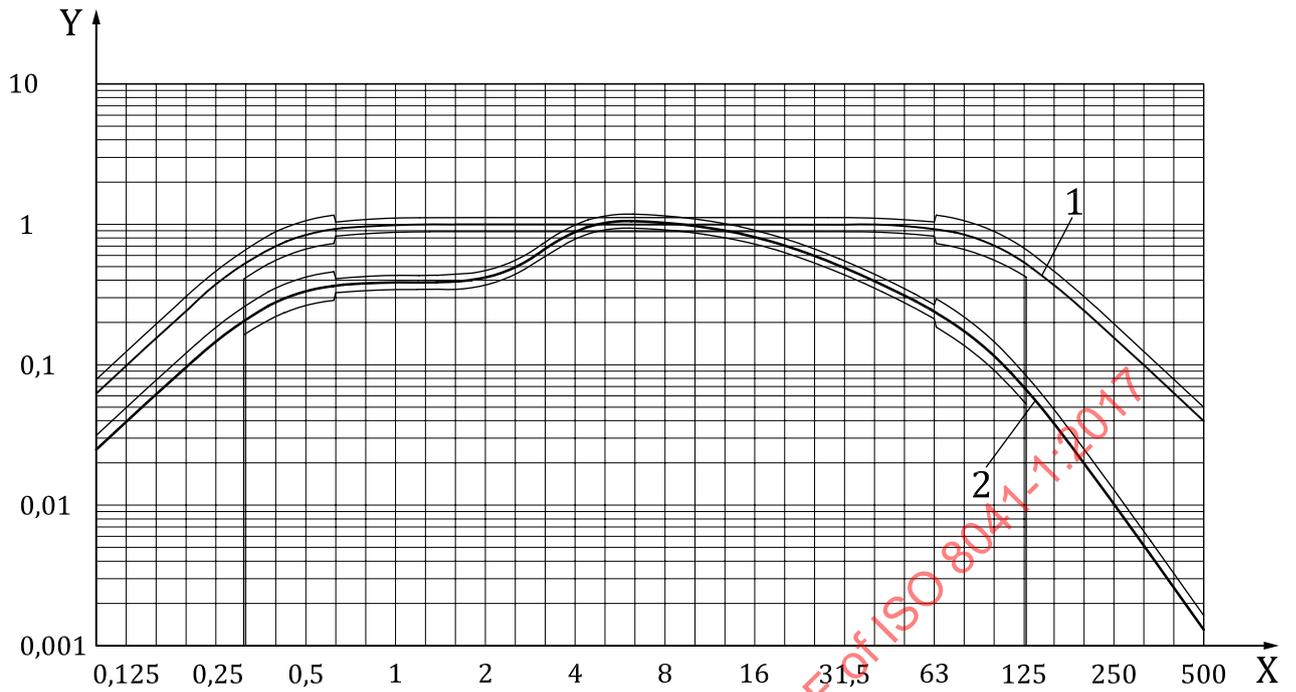
X	frequency, Hz	1	band-limiting
Y	weighting factor	2	weighting

Figure B.1 — Magnitude of frequency weighting W_b for vertical whole-body vibration, *z*-axis, seated, standing or recumbent person, based on ISO 2631-4

Key

X	frequency, Hz	1	band-limiting
Y	phase (degrees)	2	weighting

Figure B.2 — Phase of frequency weighting W_b for vertical whole-body vibration, z-axis, seated, standing or recumbent person, based on ISO 2631-4

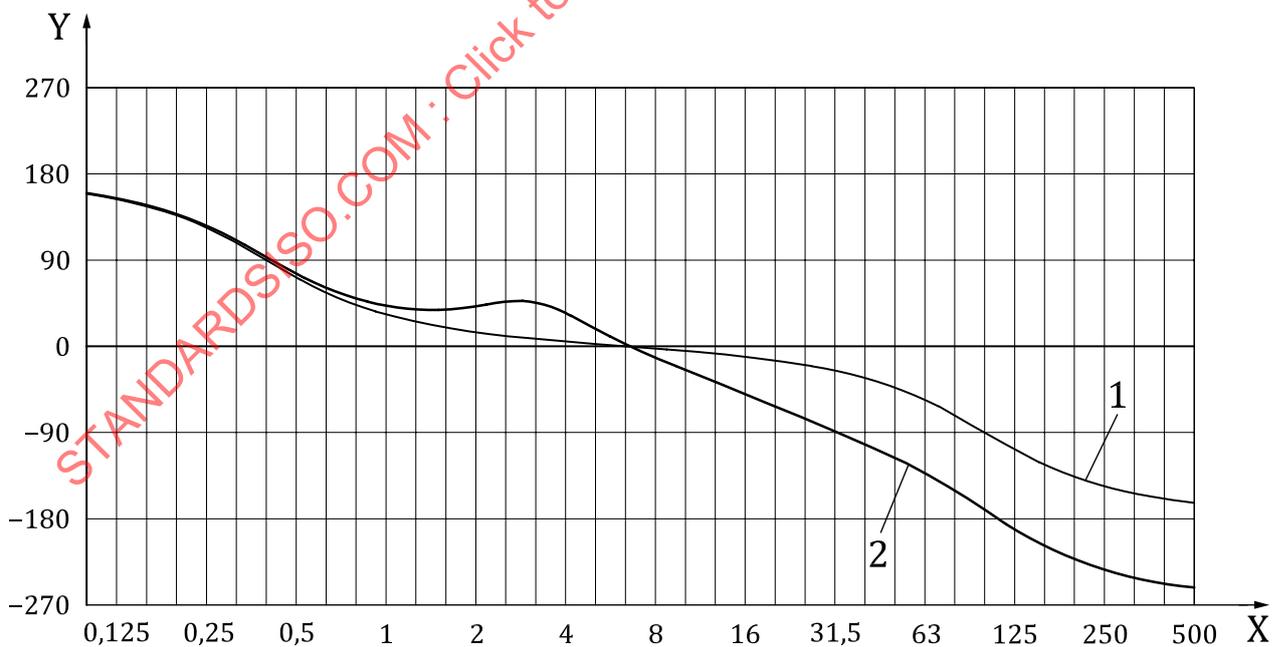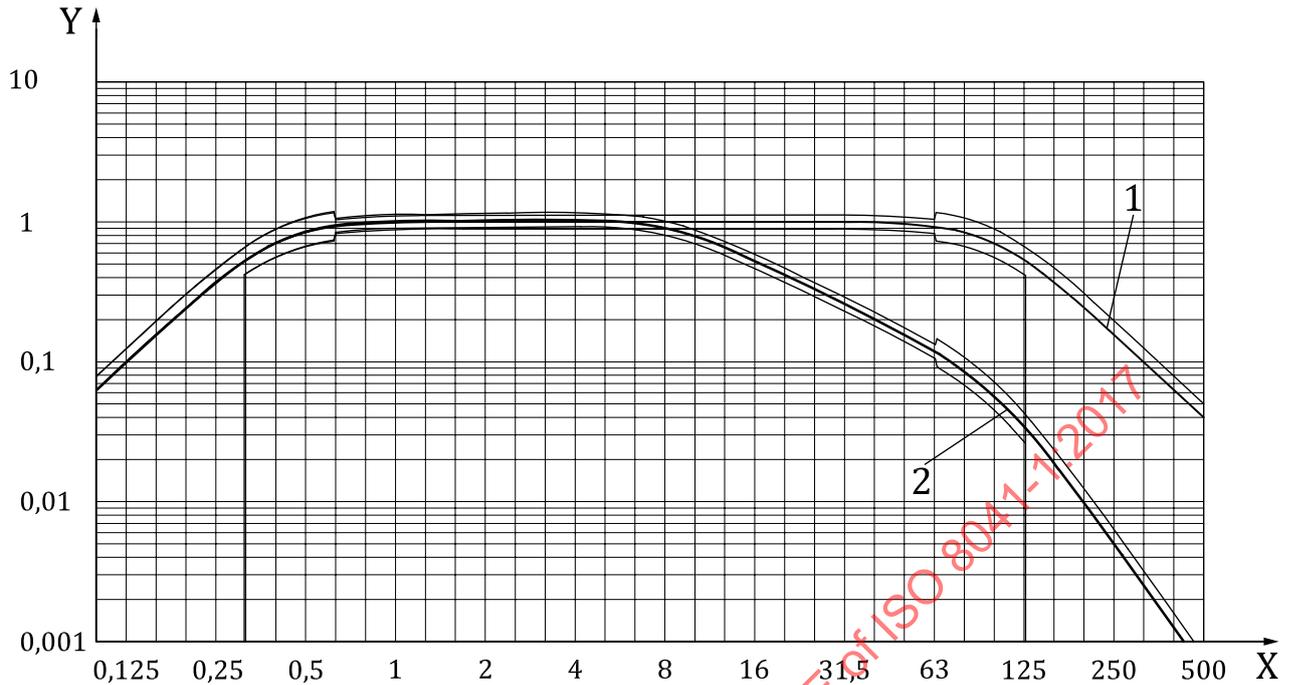**Table B.2 — Frequency weighting W_c for horizontal whole-body vibration, *x*-axis, seat back, seated person, based on ISO 2631-1**

n	Frequency Hz Nominal	True	Band-limiting Factor	dB	Phase degrees	Weighting W_c Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ degrees
−10	0,1	0,1	0,062 38	−24,10	159,3	0,062 38	−24,10	158,8	+26/−100	+2/−∞	+∞/−∞
−9	0,125	0,125 9	0,098 57	−20,12	153,6	0,098 58	−20,12	153,1	+26/−100	+2/−∞	+∞/−∞
−8	0,16	0,158 5	0,155 1	−16,19	146,3	0,155 1	−16,19	145,6	+26/−100	+2/−∞	+∞/−∞
−7	0,2	0,199 5	0,241 5	−12,34	136,6	0,241 5	−12,34	135,8	+26/−100	+2/−∞	+∞/−∞
−6	0,25	0,251 2	0,366 9	−8,71	124,1	0,366 9	−8,71	123	+26/−100	+2/−∞	+∞/−∞
−5	0,315	0,316 2	0,53	−5,51	108,3	0,530 2	−5,51	107	+26/−21	+2/−2	+12/−12
−4	0,4	0,398 1	0,703 7	−3,05	90,06	0,704 2	−3,05	88,38	+26/−21	+2/−2	+12/−12
−3	0,5	0,501 2	0,843 4	−1,48	71,76	0,844 2	−1,47	69,65	+26/−21	+2/−2	+12/−12
−2	0,63	0,631	0,927 9	−0,65	55,78	0,929 2	−0,64	53,11	+12/−11	+1/−1	+6/−6
−1	0,8	0,794 3	0,969 3	−0,27	43,01	0,971 6	−0,25	39,64	+12/−11	+1/−1	+6/−6
0	1	1	0,987 4	−0,11	33,15	0,991	−0,08	28,88	+12/−11	+1/−1	+6/−6
1	1,25	1,259	0,994 9	−0,04	25,54	1	0,00	20,11	+12/−11	+1/−1	+6/−6
2	1,6	1,585	0,998	−0,02	19,58	1,006	0,06	12,66	+12/−11	+1/−1	+6/−6
3	2	1,995	0,999 2	−0,01	14,84	1,012	0,10	5,957	+12/−11	+1/−1	+6/−6
4	2,5	2,512	0,999 7	0,00	10,97	1,017	0,15	−0,531 8	+12/−11	+1/−1	+6/−6
5	3,15	3,162	0,999 9	0,00	7,74	1,023	0,19	−7,327	+12/−11	+1/−1	+6/−6
6	4	3,981	0,999 9	0,00	4,941	1,024	0,21	−15	+12/−11	+1/−1	+6/−6
7	5	5,012	1	0,00	2,416	1,013	0,11	−24,1	+12/−11	+1/−1	+6/−6
8	6,3	6,31	1	0,00	0,024 4	0,973 9	−0,23	−34,91	+12/−11	+1/−1	+6/−6
9	8	7,943	1	0,00	−2,366	0,894 1	−0,97	−47,06	+12/−11	+1/−1	+6/−6
10	10	10	0,999 9	0,00	−4,887	0,776 2	−2,20	−59,37	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,999 9	0,00	−7,679	0,642 5	−3,84	−70,7	+12/−11	+1/−1	+6/−6
12	16	15,85	0,999 7	0,00	−10,9	0,516 6	−5,74	−80,61	+12/−11	+1/−1	+6/−6
13	20	19,95	0,999 2	−0,01	−14,75	0,409 8	−7,75	−89,43	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	−19,47	0,323 6	−9,80	−97,78	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,995	−0,04	−25,4	0,254 9	−11,87	−106,4	+12/−11	+1/−1	+6/−6
16	40	39,81	0,987 7	−0,11	−32,97	0,200 2	−13,97	−115,9	+12/−11	+1/−1	+6/−6
17	50	50,12	0,969 9	−0,27	−42,78	0,155 7	−16,15	−127,3	+12/−11	+1/−1	+6/−6
18	63	63,1	0,929 1	−0,64	−55,49	0,118 2	−18,55	−141,2	+12/−11	+1/−1	+6/−6
19	80	79,43	0,845 7	−1,46	−71,41	0,085 38	−21,37	−158	+26/−21	+2/−2	+12/−12
20	100	100	0,707 1	−3,01	−89,68	0,056 65	−24,94	−177	+26/−21	+2/−2	+12/−12
21	125	125,9	0,533 6	−5,46	−107,9	0,033 94	−29,39	−195,8	+26/−21	+2/−2	+12/−12
22	160	158,5	0,369 9	−8,64	−123,8	0,018 68	−34,57	−212,1	+26/−100	+2/−∞	+∞/−∞
23	200	199,5	0,243 6	−12,27	−136,4	0,009 772	−40,20	−225,1	+26/−100	+2/−∞	+∞/−∞
24	250	251,2	0,156 5	−16,11	−146,1	0,004 987	−46,04	−235	+26/−100	+2/−∞	+∞/−∞
25	315	316,2	0,099 5	−20,04	−153,5	0,002 518	−51,98	−242,6	+26/−100	+2/−∞	+∞/−∞
26	400	398,1	0,062 97	−24,02	−159,2	0,001 266	−57,95	−248,5	+26/−100	+2/−∞	+∞/−∞

Key

X   frequency, Hz

Y   weighting factor

1   band-limiting

2   weighting

Figure B.3 — Magnitude of frequency weighting W_c for horizontal whole-body vibration, *x*-axis, seat back, seated person, based on ISO 2631-1

Key

X   frequency, Hz

Y   phase (degrees)

1   band-limiting

2   weighting

Figure B.4 — Phase of frequency weighting W_c for horizontal whole-body vibration, *x*-axis, seat back, seated person, based on ISO 2631-1
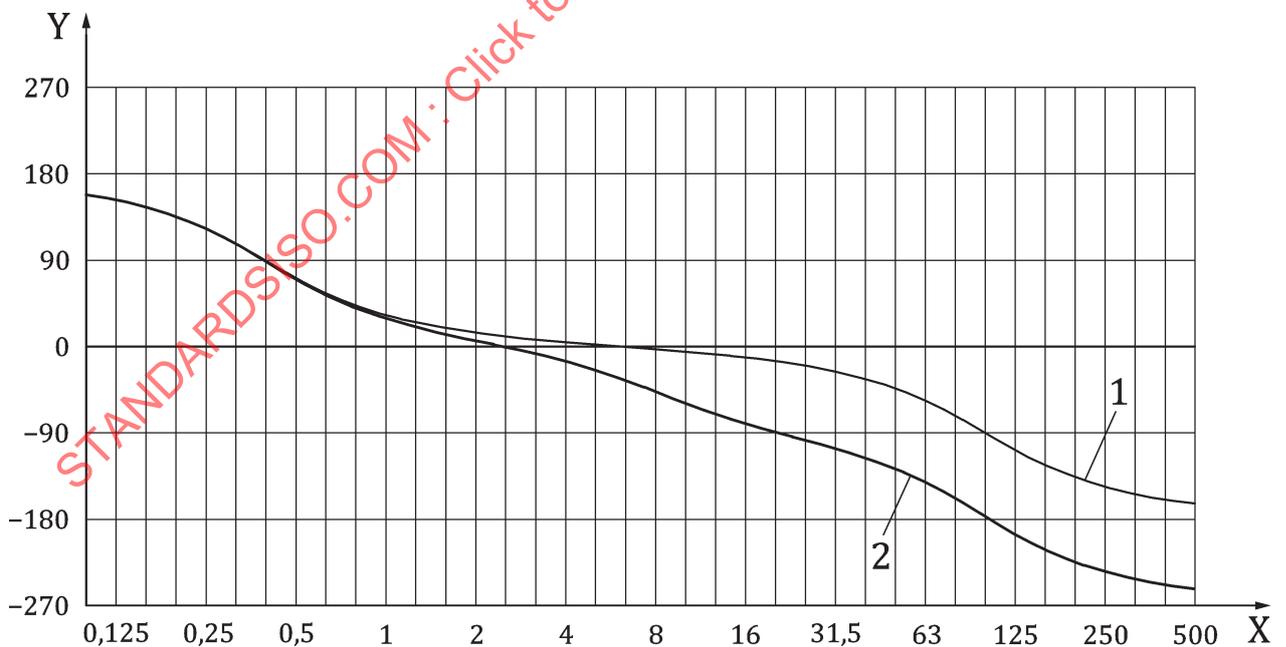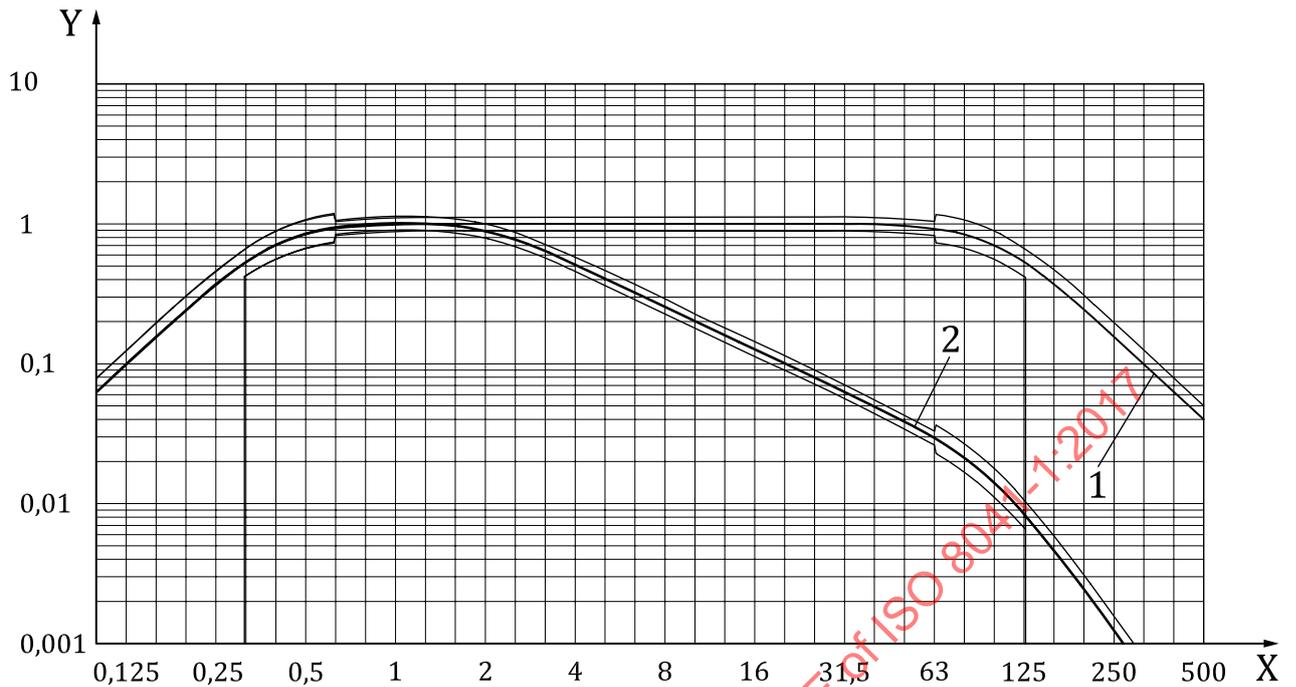
Table B.3 — Frequency weighting W_d for horizontal whole-body vibration, *x*- or *y*-axis, seated, standing or recumbent person, based on ISO 2631-1

n	Frequency Hz Nominal	True	Band-limiting Factor	dB	Phase degrees	Weighting, W_d Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ degrees
−10	0,1	0,1	0,062 38	−24,10	159,3	0,062 42	−24,09	157,6	+26/−100	+2/−∞	+∞/−∞
−9	0,125	0,125 9	0,098 57	−20,12	153,6	0,098 67	−20,12	151,5	+26/−100	+2/−∞	+∞/−∞
−8	0,16	0,158 5	0,155 1	−16,19	146,3	0,155 3	−16,18	143,6	+26/−100	+2/−∞	+∞/−∞
−7	0,2	0,199 5	0,241 5	−12,34	136,6	0,242	−12,32	133,2	+26/−100	+2/−∞	+∞/−∞
−6	0,25	0,251 2	0,366 9	−8,71	124,1	0,368 2	−8,68	119,8	+26/−100	+2/−∞	+∞/−∞
−5	0,315	0,316 2	0,53	−5,51	108,3	0,533	−5,47	102,8	+26/−21	+2/−2	+12/−12
−4	0,4	0,398 1	0,703 7	−3,05	90,06	0,709 7	−2,98	83,11	+26/−21	+2/−2	+12/−12
−3	0,5	0,501 2	0,843 4	−1,48	71,76	0,854	−1,37	62,84	+26/−21	+2/−2	+12/−12
−2	0,63	0,631	0,927 9	−0,65	55,78	0,944 3	−0,50	44,21	+12/−11	+1/−1	+6/−6
−1	0,8	0,794 3	0,969 3	−0,27	43,01	0,991 4	−0,08	27,86	+12/−11	+1/−1	+6/−6
0	1	1	0,987 4	−0,11	33,15	1,011	0,10	13,09	+12/−11	+1/−1	+6/−6
1	1,25	1,259	0,994 9	−0,04	25,54	1,007	0,06	−1,131	+12/−11	+1/−1	+6/−6
2	1,6	1,585	0,998	−0,02	19,58	0,970 7	−0,26	−15,55	+12/−11	+1/−1	+6/−6
3	2	1,995	0,999 2	−0,01	14,84	0,891 3	−1,00	−30,06	+12/−11	+1/−1	+6/−6
4	2,5	2,512	0,999 7	0,00	10,97	0,773 3	−2,23	−43,71	+12/−11	+1/−1	+6/−6
5	3,15	3,162	0,999 9	0,00	7,74	0,639 8	−3,88	−55,44	+12/−11	+1/−1	+6/−6
6	4	3,981	0,999 9	0,00	4,941	0,514 3	−5,78	−64,89	+12/−11	+1/−1	+6/−6
7	5	5,012	1	0,00	2,416	0,408 1	−7,78	−72,34	+12/−11	+1/−1	+6/−6
8	6,3	6,31	1	0,00	0,024 4	0,322 6	−9,83	−78,34	+12/−11	+1/−1	+6/−6
9	8	7,943	1	0,00	−2,366	0,255	−11,87	−83,39	+12/−11	+1/−1	+6/−6
10	10	10	0,999 9	0,00	−4,887	0,201 7	−13,91	−87,9	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,999 9	0,00	−7,679	0,159 7	−15,93	−92,2	+12/−11	+1/−1	+6/−6
12	16	15,85	0,999 7	0,00	−10,9	0,126 6	−17,95	−96,59	+12/−11	+1/−1	+6/−6
13	20	19,95	0,999 2	−0,01	−14,75	0,100 4	−19,97	−101,3	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	−19,47	0,079 58	−21,98	−106,8	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,995	−0,04	−25,4	0,062 99	−24,01	−113,3	+12/−11	+1/−1	+6/−6
16	40	39,81	0,987 7	−0,11	−32,97	0,049 65	−26,08	−121,3	+12/−11	+1/−1	+6/−6
17	50	50,12	0,969 9	−0,27	−42,78	0,038 72	−28,24	−131,4	+12/−11	+1/−1	+6/−6
18	63	63,1	0,929 1	−0,64	−55,49	0,029 46	−30,62	−144,4	+12/−11	+1/−1	+6/−6
19	80	79,43	0,845 7	−1,46	−71,41	0,021 3	−33,43	−160,6	+26/−21	+2/−2	+12/−12
20	100	100	0,707 1	−3,01	−89,68	0,014 14	−36,99	−179	+26/−21	+2/−2	+12/−12
21	125	125,9	0,533 6	−5,46	−107,9	0,008 478	−41,43	−197,4	+26/−21	+2/−2	+12/−12
22	160	158,5	0,369 9	−8,64	−123,8	0,004 668	−46,62	−213,4	+26/−100	+2/−∞	+∞/−∞
23	200	199,5	0,243 6	−12,27	−136,4	0,002 442	−52,24	−226,1	+26/−100	+2/−∞	+∞/−∞
24	250	251,2	0,156 5	−16,11	−146,1	0,001 246	−58,09	−235,8	+26/−100	+2/−∞	+∞/−∞
25	315	316,2	0,099 5	−20,04	−153,5	0,000 629 3	−64,02	−243,3	+26/−100	+2/−∞	+∞/−∞
26	400	398,1	0,062 97	−24,02	−159,2	0,000 316 4	−70,00	−249	+26/−100	+2/−∞	+∞/−∞

Key

X   frequency, Hz

Y   weighting factor

1   band-limiting

2   weighting

Figure B.5 — Magnitude of frequency weighting W_d for horizontal whole-body vibration, *x*- or *y*-axis, seated, standing or recumbent person, based on ISO 2631-1

Key
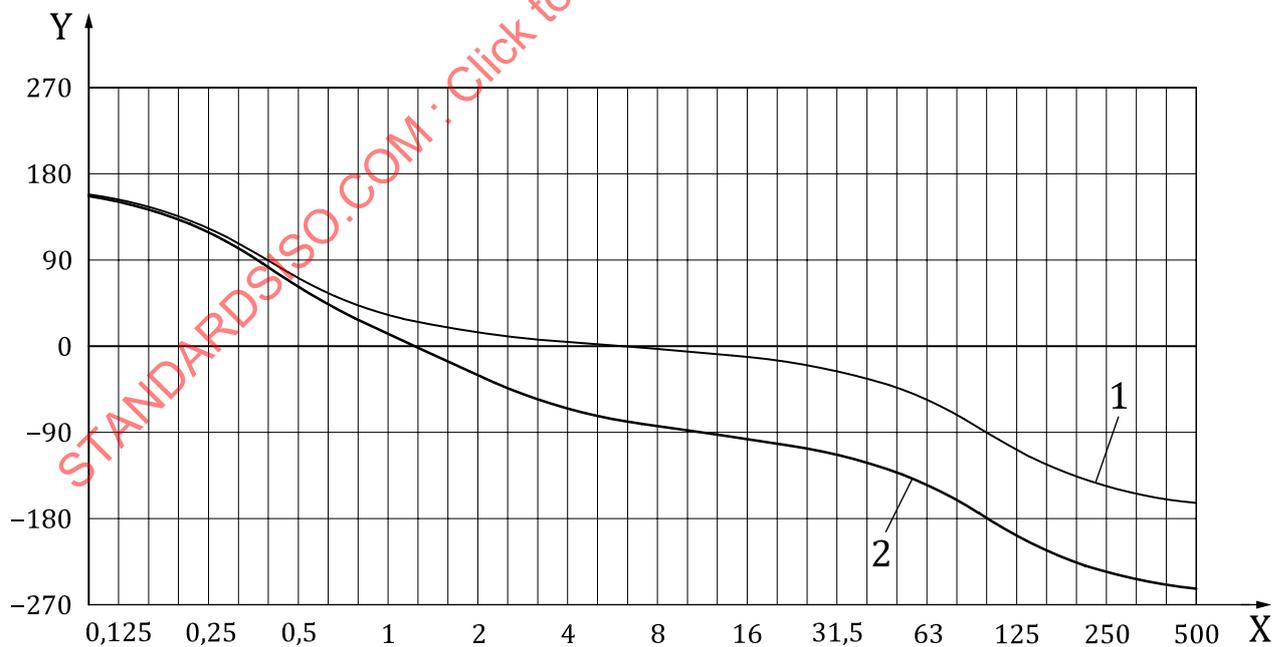
X   frequency, Hz

Y   phase (degrees)

1   band-limiting

2   weighting

Figure B.6 — Phase of frequency weighting W_d for horizontal whole-body vibration, *x*- or *y*-axis seated, standing or recumbent person, based on ISO 2631-1
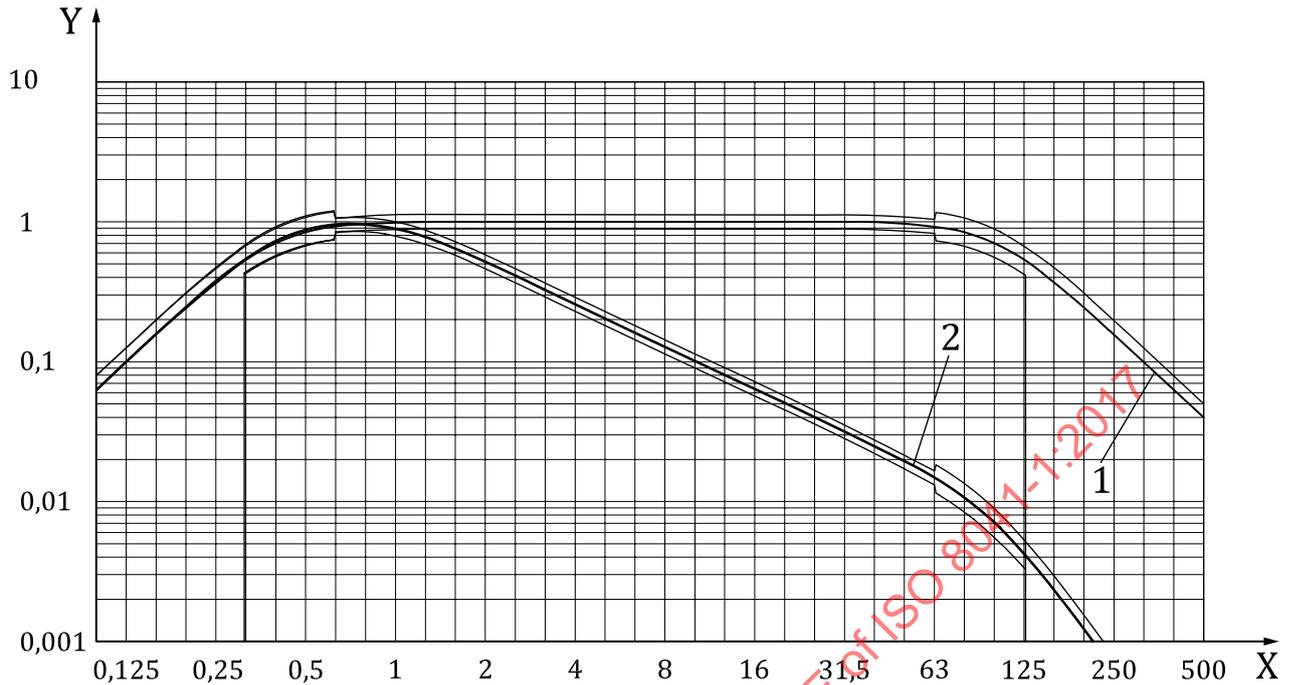
Table B.4 — Frequency weighting W_e for rotational whole-body vibration, all directions, seated person, based on ISO 2631-1

n	Frequency Hz Nominal	True	Band-limiting Factor	dB	Phase degrees	Weighting, W_e Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ degrees
−10	0,1	0,1	0,062 38	−24,10	159,3	0,062 52	−24,08	155,9	+26/−100	+2/−∞	+∞/−∞
−9	0,125	0,125 9	0,098 57	−20,12	153,6	0,098 93	−20,09	149,3	+26/−100	+2/−∞	+∞/−∞
−8	0,16	0,158 5	0,155 1	−16,19	146,3	0,156	−16,14	140,8	+26/−100	+2/−∞	+∞/−∞
−7	0,2	0,199 5	0,241 5	−12,34	136,6	0,243 5	−12,27	129,7	+26/−100	+2/−∞	+∞/−∞
−6	0,25	0,251 2	0,366 9	−8,71	124,1	0,371 5	−8,60	115,1	+26/−100	+2/−∞	+∞/−∞
−5	0,315	0,316 2	0,53	−5,51	108,3	0,539 4	−5,36	96,68	+26/−21	+2/−2	+12/−12
−4	0,4	0,398 1	0,703 7	−3,05	90,06	0,719 8	−2,86	74,87	+26/−21	+2/−2	+12/−12
−3	0,5	0,501 2	0,843 4	−1,48	71,76	0,863 5	−1,27	51,65	+26/−21	+2/−2	+12/−12
−2	0,63	0,631	0,927 9	−0,65	55,78	0,938 9	−0,55	29,04	+12/−11	+1/−1	+6/−6
−1	0,8	0,794 3	0,969 3	−0,27	43,01	0,942 3	−0,52	7,786	+12/−11	+1/−1	+6/−6
0	1	1	0,987 4	−0,11	33,15	0,879 8	−1,11	−11,85	+12/−11	+1/−1	+6/−6
1	1,25	1,259	0,994 9	−0,04	25,54	0,768 3	−2,29	−29,24	+12/−11	+1/−1	+6/−6
2	1,6	1,585	0,998	−0,02	19,58	0,637 2	−3,91	−43,67	+12/−11	+1/−1	+6/−6
3	2	1,995	0,999 2	−0,01	14,84	0,512 7	−5,80	−55,05	+12/−11	+1/−1	+6/−6
4	2,5	2,512	0,999 7	0,00	10,97	0,407	−7,81	−63,83	+12/−11	+1/−1	+6/−6
5	3,15	3,162	0,999 9	0,00	7,74	0,321 8	−9,85	−70,66	+12/−11	+1/−1	+6/−6
6	4	3,981	0,999 9	0,00	4,941	0,254 3	−11,89	−76,11	+12/−11	+1/−1	+6/−6
7	5	5,012	1	0,00	2,416	0,201 2	−13,93	−80,61	+12/−11	+1/−1	+6/−6
8	6,3	6,31	1	0,00	0,024 4	0,159 4	−15,95	−84,51	+12/−11	+1/−1	+6/−6
9	8	7,943	1	0,00	−2,366	0,126 3	−17,97	−88,06	+12/−11	+1/−1	+6/−6
10	10	10	0,999 9	0,00	−4,887	0,100 2	−19,98	−91,49	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,999 9	0,00	−7,679	0,079 54	−21,99	−94,99	+12/−11	+1/−1	+6/−6
12	16	15,85	0,999 7	0,00	−10,9	0,063 14	−23,99	−98,77	+12/−11	+1/−1	+6/−6
13	20	19,95	0,999 2	−0,01	−14,75	0,050 11	−26,00	−103,1	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	−19,47	0,039 75	−28,01	−108,1	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,995	−0,04	−25,4	0,031 47	−30,04	−114,3	+12/−11	+1/−1	+6/−6
16	40	39,81	0,987 7	−0,11	−32,97	0,024 81	−32,11	−122,1	+12/−11	+1/−1	+6/−6
17	50	50,12	0,969 9	−0,27	−42,78	0,019 35	−34,26	−132,1	+12/−11	+1/−1	+6/−6
18	63	63,1	0,929 1	−0,64	−55,49	0,014 73	−36,64	−145	+12/−11	+1/−1	+6/−6
19	80	79,43	0,845 7	−1,46	−71,41	0,010 65	−39,46	−161	+26/−21	+2/−2	+12/−12
20	100	100	0,707 1	−3,01	−89,68	0,007 071	−43,01	−179,3	+26/−21	+2/−2	+12/−12
21	125	125,9	0,533 6	−5,46	−107,9	0,004 239	−47,46	−197,7	+26/−21	+2/−2	+12/−12
22	160	158,5	0,369 9	−8,64	−123,8	0,00 233 4	−52,64	−213,6	+26/−100	+2/−∞	+∞/−∞
23	200	199,5	0,243 6	−12,27	−136,4	0,00 122 1	−58,27	−226,2	+26/−100	+2/−∞	+∞/−∞
24	250	251,2	0,156 5	−16,11	−146,1	0,000 623 2	−64,11	−236	+26/−100	+2/−∞	+∞/−∞
25	315	316,2	0,099 5	−20,04	−153,5	0,000 314 7	−70,04	−243,4	+26/−100	+2/−∞	+∞/−∞
26	400	398,1	0,062 97	−24,02	−159,2	0,000 1582	−76,02	−249,1	+26/−100	+2/−∞	+∞/−∞

Key

X	frequency, Hz	1	band-limiting
Y	weighting factor	2	weighting

Figure B.7 — Magnitude of frequency weighting W_e for rotational whole-body vibration, all directions, seated person, based on ISO 2631-1

Key
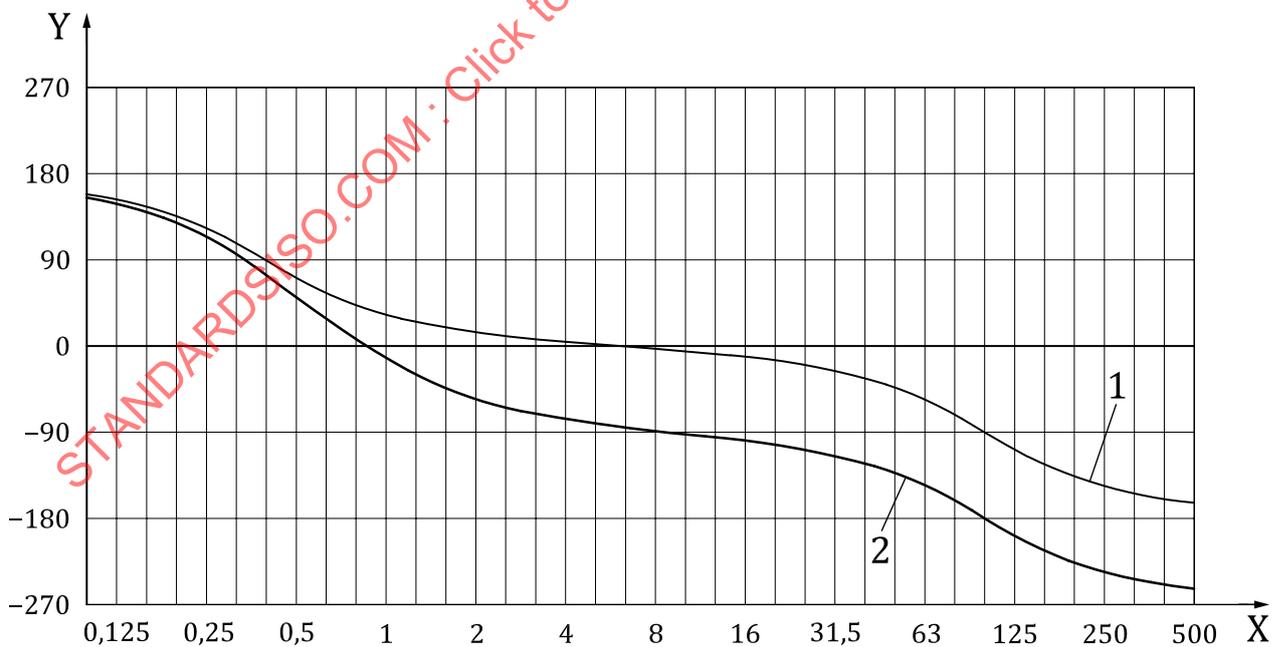
X	frequency, Hz	1	band-limiting
Y	phase (degrees)	2	weighting

Figure B.8 — Phase of frequency weighting W_e for rotational whole-body vibration, all directions, seated person, based on ISO 2631-1
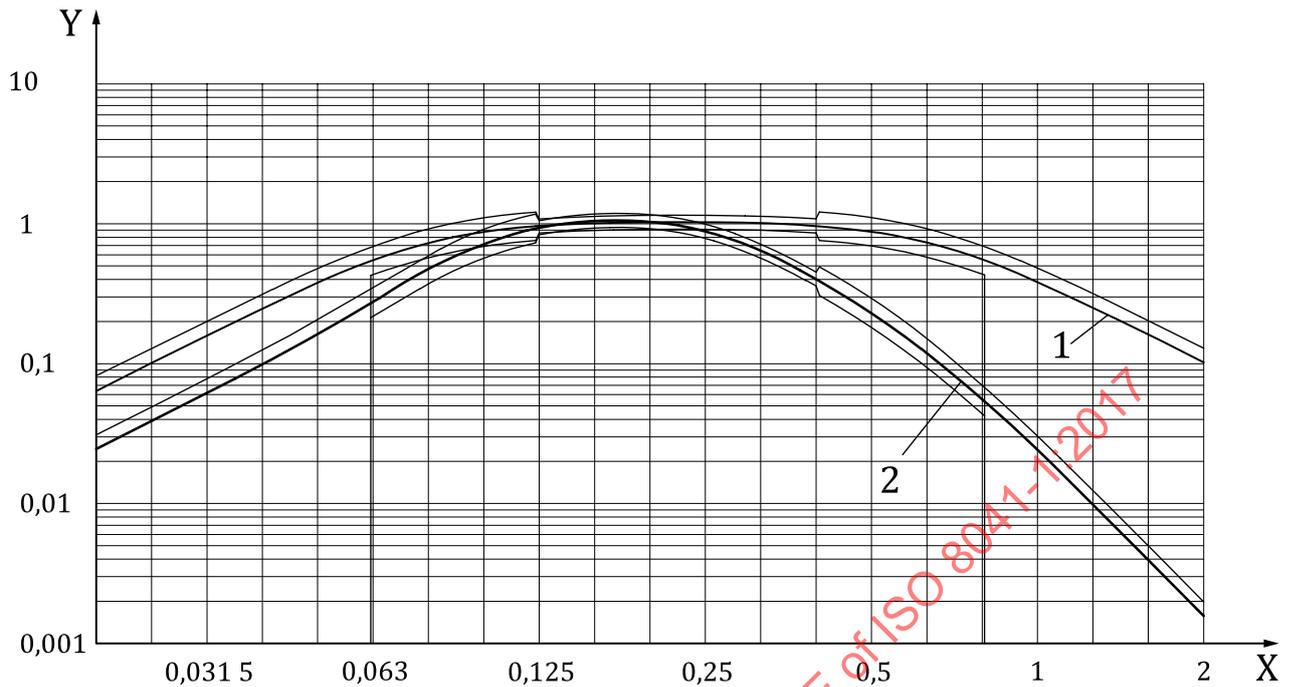
Table B.5 — Frequency weighting W_f for vertical whole-body vibration, z-axis motion sickness, seated or standing person, based on ISO 2631-1

n	Frequency Hz Nomi-nal	True	Band-limiting Factor	dB	Phase degrees	Weighting, W_f Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ de-grees
−17	0,02	0,019 95	0,062 08	−24,14	156,8	0,024 07	−32,37	160,9	+26/−100	+2/−∞	+∞/−∞
−16	0,025	0,025 12	0,098 11	−20,17	150,5	0,038 03	−28,40	156,2	+26/−100	+2/−∞	+∞/−∞
−15	0,0315	0,031 62	0,154 4	−16,23	142,4	0,060 21	−24,41	150,6	+26/−100	+2/−∞	+∞/−∞
−14	0,04	0,039 81	0,240 4	−12,38	131,8	0,096 19	−20,34	143,7	+26/−100	+2/−∞	+∞/−∞
−13	0,05	0,050 12	0,365 3	−8,75	118	0,157 5	−16,06	134,8	++26/−100	+2/−∞	+∞/−∞
−12	0,063	0,063 1	0,528 2	−5,54	100,6	0,267 5	−11,45	121,4	+26/−21	+2/−2	+12/−12
−11	0,08	0,079 43	0,702	−3,07	80,31	0,453 7	−6,86	99,53	+26/−21	+2/−2	+12/−12
−10	0,1	0,1	0,842	−1,49	59,38	0,695 1	−3,16	68,36	+26/−21	+2/−2	+12/−12
−9	0,125	0,125 9	0,926 5	−0,66	40,04	0,9	−0,92	32,06	+12/−11	+1/−1	+6/−6
−8	0,16	0,158 5	0,967 1	−0,29	22,97	1,004	0,04	−5,596	+12/−11	+1/−1	+6/−6
−7	0,2	0,199 5	0,982 4	−0,15	7,579	0,992 8	−0,06	−44,61	+12/−11	+1/−1	+6/−6
−6	0,25	0,251 2	0,982 6	−0,15	−7,217	0,850 1	−1,41	−85,43	+12/−11	+1/−1	+6/−6
−5	0,315	0,316 2	0,967 7	−0,29	−22,58	0,614 9	−4,22	−125,5	+12/−11	+1/−1	+6/−6
−4	0,4	0,398 1	0,927 9	−0,65	−39,6	0,388 4	−8,22	−162,1	+12/−11	+1/−1	+6/−6
−3	0,5	0,501 2	0,844 7	−1,47	−58,89	0,222 2	−13,05	−195,6	+26/−21	+2/−2	+12/−12
−2	0,63	0,631	0,705 9	−3,02	−79,79	0,115 7	−18,73	−226,8	+26/−21	+2/−2	+12/−12
−1	0,8	0,794 3	0,532 4	−5,47	−100,1	0,054 34	−25,30	−254,6	+26/−21	+2/−2	+12/−12
0	1	1	0,368 9	−8,66	−117,6	0,023 52	−32,57	−277,7	+26/−100	+2/−∞	+∞/−∞
1	1,25	1,259	0,242 9	−12,29	−131,5	0,009 705	−40,26	−295,8	+26/−100	+2/−∞	+∞/−∞
2	1,6	1,585	0,156 1	−16,13	−142,2	0,003 916	−48,14	−309,8	+26/−100	+2/−∞	+∞/−∞
3	2	1,995	0,099 2	−20,07	−150,4	0,001 566	−56,11	−320,6	+26/−100	+2/−∞	+∞/−∞

Key

X	frequency, Hz	1	band-limiting
Y	weighting factor	2	weighting

Figure B.9 — Magnitude of frequency weighting W_f for vertical whole-body vibration, z-axis motion sickness, seated or standing person, based on ISO 2631-1

Key

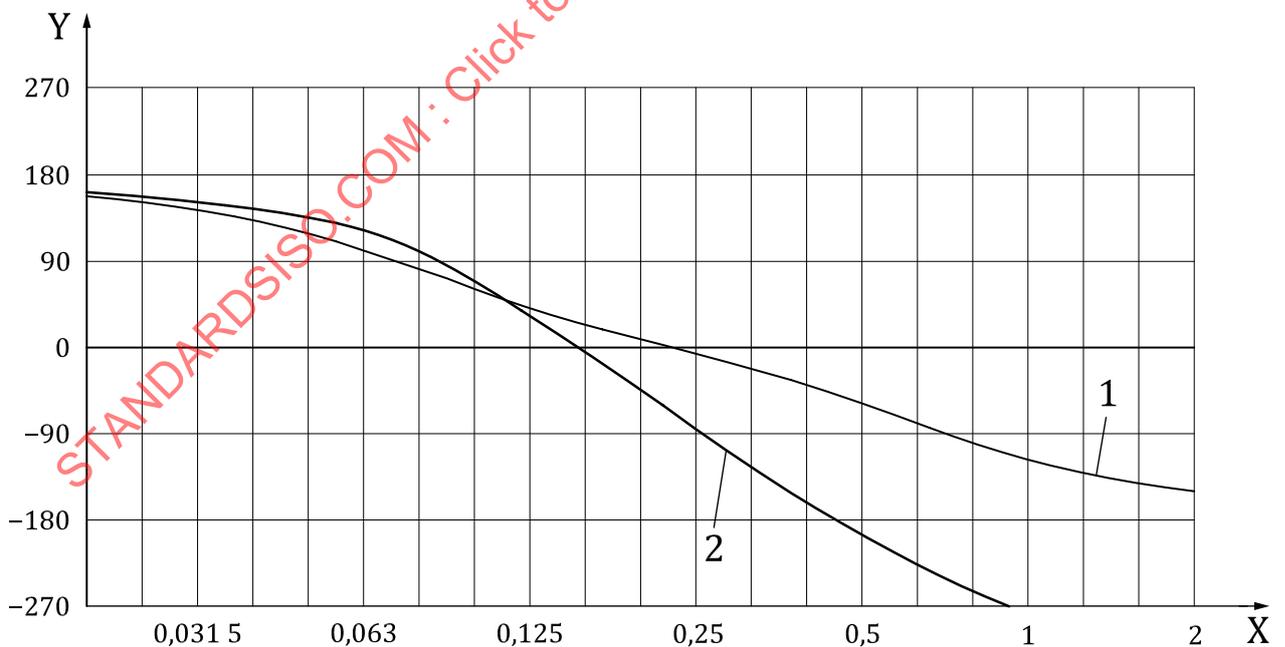|			
X	frequency, Hz	1	band-limiting
Y	phase (degrees)	2	weighting

Figure B.10 — Phase of frequency weighting W_f for vertical whole-body vibration, *z*-axis motion sickness, seated or standing person, based on ISO 2631-1
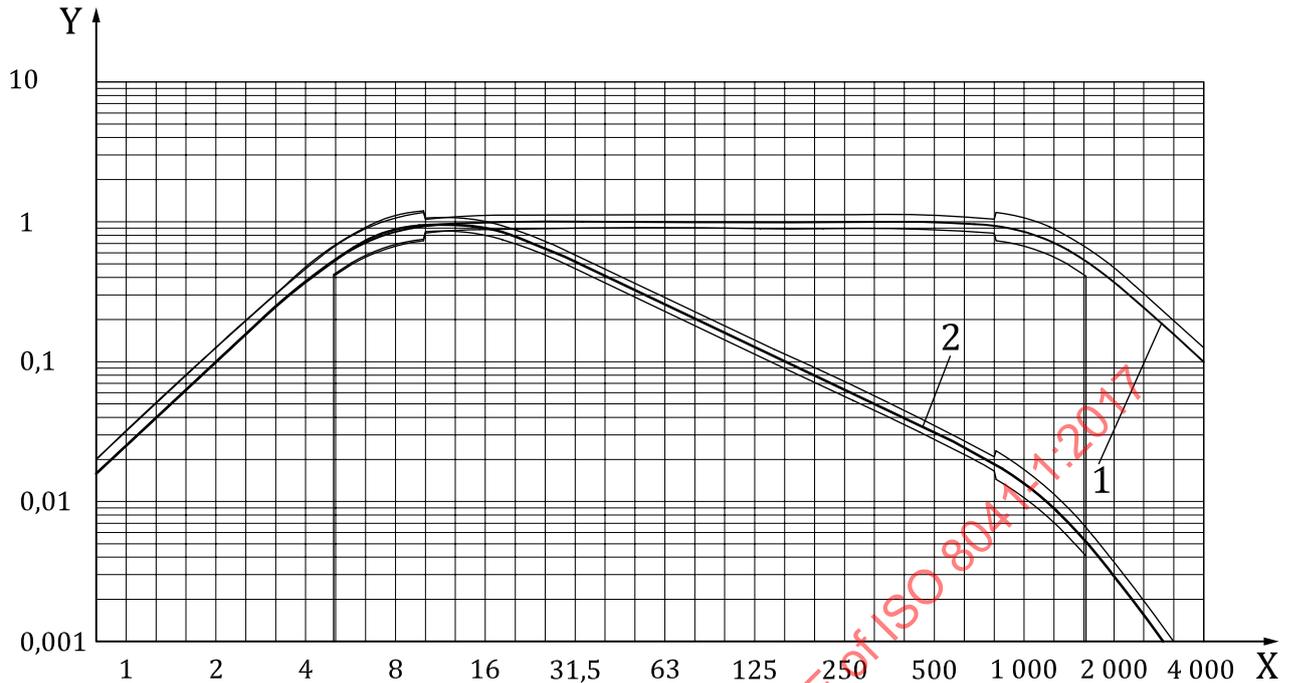
Table B.6 — Frequency weighting W_h for hand-arm vibration, all directions, based on ISO 5349-1

n	Frequency Hz Nominal	True	Band-limiting Factor	dB	Phase degrees	Weighting, W_h Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ degrees
−1	0,8	0,794 3	0,015 85	−36,00	169,7	0,015 86	−36,00	168,1	+26/−100	+2/−∞	+∞/−∞
0	1	1	0,025 11	−32,00	167	0,025 14	−31,99	165	+26/−100	+2/−∞	+∞/−∞
1	1,25	1,259	0,039 78	−28,01	163,5	0,039 85	−27,99	161	+26/−100	+2/−∞	+∞/−∞
2	1,6	1,585	0,062 97	−24,02	159,1	0,063 14	−23,99	155,9	+26/−100	+2/−∞	+∞/−∞
3	2	1,995	0,099 5	−20,04	153,4	0,099 92	−20,01	149,3	+26/−100	+2/−∞	+∞/−∞
4	2,5	2,512	0,156 5	−16,11	146,1	0,157 6	−16,05	140,8	+26/−100	+2/−∞	+∞/−∞
5	3,15	3,162	0,243 6	−12,27	136,4	0,246 1	−12,18	129,7	+26/−100	+2/−∞	+∞/−∞
6	4	3,981	0,369 9	−8,64	123,7	0,375 4	−8,51	115,2	+26/−100	+2/−∞	+∞/−∞
7	5	5,012	0,533 6	−5,46	107,9	0,545	−5,27	96,7	+26/−21	+2/−2	+12/−12
8	6,3	6,31	0,707 1	−3,01	89,59	0,727 2	−2,77	74,91	+26/−21	+2/−2	+12/−12
9	8	7,943	0,845 7	−1,46	71,3	0,873 1	−1,18	51,74	+26/−21	+2/−2	+12/−12
10	10	10	0,929 1	−0,64	55,36	0,951 4	−0,43	29,15	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,969 9	−0,27	42,62	0,957 6	−0,38	7,81	+12/−11	+1/−1	+6/−6
12	16	15,85	0,987 7	−0,11	32,76	0,895 8	−0,96	−12,05	+12/−11	+1/−1	+6/−6
13	20	19,95	0,995	−0,04	25,14	0,782	−2,14	−29,71	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	19,15	0,647 1	−3,78	−44,37	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,999 2	−0,01	14,34	0,519 2	−5,69	−55,89	+12/−11	+1/−1	+6/−6
16	40	39,81	0,999 7	0,00	10,38	0,411 1	−7,72	−64,78	+12/−11	+1/−1	+6/−6
17	50	50,12	0,999 9	0,00	7,027	0,324 4	−9,78	−71,7	+12/−11	+1/−1	+6/−6
18	63	63,1	0,999 9	0,00	4,065	0,256	−11,83	−77,27	+12/−11	+1/−1	+6/−6
19	80	79,43	1	0,00	1,33	0,202 4	−13,88	−81,94	+12/−11	+1/−1	+6/−6
20	100	100	1	0,00	−1,33	0,160 2	−15,91	−86,06	+12/−11	+1/−1	+6/−6
21	125	125,9	0,999 9	0,00	−4,065	0,127	−17,93	−89,92	+12/−11	+1/−1	+6/−6
22	160	158,5	0,999 9	0,00	−7,027	0,100 7	−19,94	−93,75	+12/−11	+1/−1	+6/−6
23	200	199,5	0,999 7	0,00	−10,38	0,079 88	−21,95	−97,8	+12/−11	+1/−1	+6/−6
24	250	251,2	0,999 2	−0,01	−14,34	0,063 38	−23,96	−102,3	+12/−11	+1/−1	+6/−6
25	315	316,2	0,998	−0,02	−19,15	0,050 26	−25,97	−107,5	+12/−11	+1/−1	+6/−6
26	400	398,1	0,995	−0,04	−25,14	0,039 8	−28,00	−113,8	+12/−11	+1/−1	+6/−6
27	500	501,2	0,987 7	−0,11	−32,76	0,031 37	−30,07	−121,7	+12/−11	+1/−1	+6/−6
28	630	631	0,969 9	−0,27	−42,62	0,024 47	−32,23	−131,8	+12/−11	+1/−1	+6/−6
29	800	794,3	0,929 1	−0,64	−55,36	0,018 62	−34,60	−144,7	+12/−11	+1/−1	+6/−6
30	1 000	1 000	0,845 7	−1,46	−71,3	0,013 46	−37,42	−160,8	+26/−21	+2/−2	+12/−12
31	1 250	1 259	0,707 1	−3,01	−89,59	0,008 94	−40,97	−179,2	+26/−21	+2/−2	+12/−12
32	1 600	1585	0,533 6	−5,46	−107,9	0,005 359	−45,42	−197,5	+26/−21	+2/−2	+12/−12
33	2 000	1995	0,369 9	−8,64	−123,7	0,002 95	−50,60	−213,5	+26/−100	+2/−∞	+∞/−∞
34	2 500	2512	0,243 6	−12,27	−136,4	0,001 544	−56,23	−226,2	+26/−100	+2/−∞	+∞/−∞
35	3 150	3162	0,156 5	−16,11	−146,1	0,000 787 8	−62,07	−235,9	+26/−100	+2/−∞	+∞/−∞
36	4 000	3981	0,099 5	−20,04	−153,4	0,000 397 8	−68,01	−243,3	+26/−100	+2/−∞	+∞/−∞

Key

X	frequency, Hz	1	band-limiting
Y	weighting factor	2	weighting

Figure B.11 — Magnitude of frequency weighting W_h for hand-arm vibration, all directions, based on ISO 5349-1
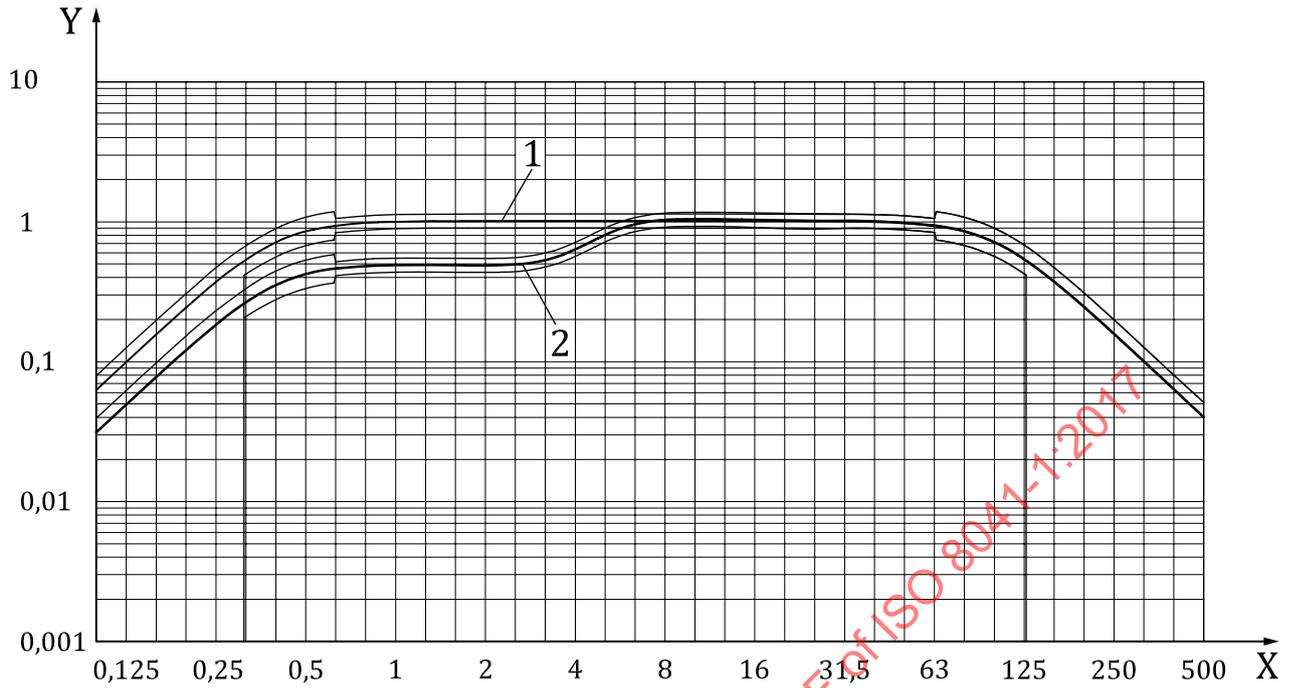

Key
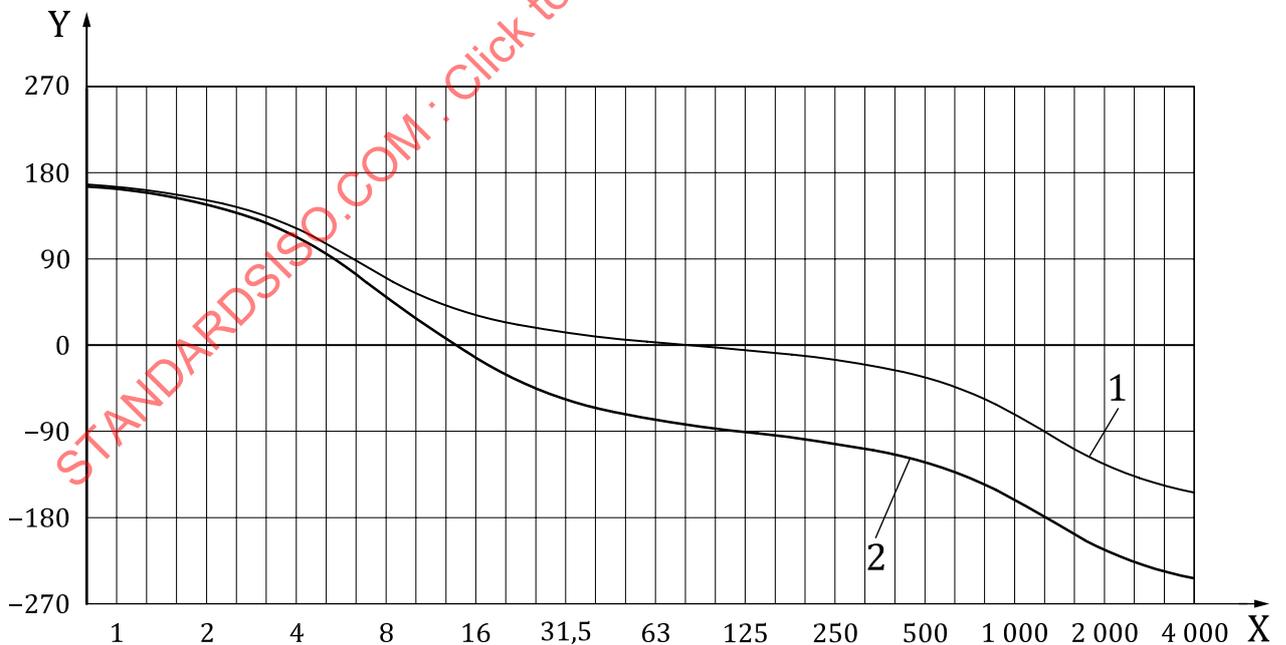
X	frequency, Hz	1	band-limiting
Y	phase (degrees)	2	weighting

Figure B.12 — Phase of frequency weighting W_h for hand-arm vibration, all directions, based on ISO 5349-1

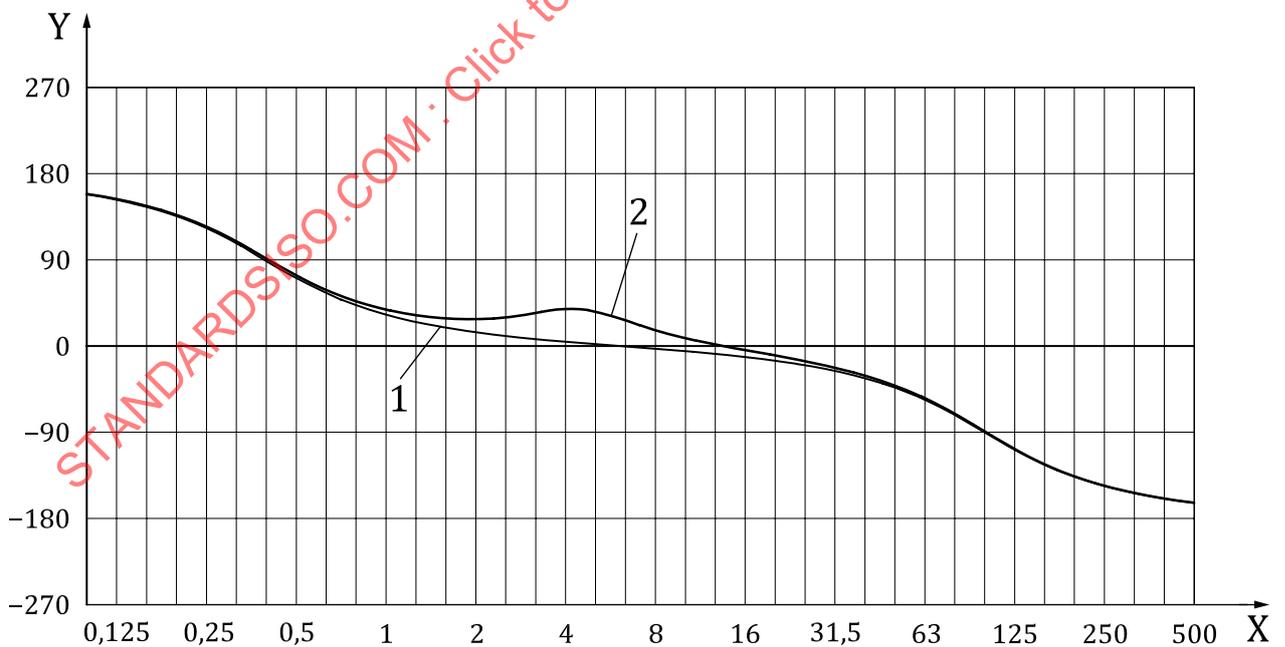**Table B.7 — Frequency weighting W_j for vertical head vibration, *x*-axis recumbent person, based on ISO 2631-1**

n	Frequency Hz Nominal	Frequency Hz True	Band-limiting Factor	Band-limiting dB	Band-limiting Phase degrees	Weighting, W_j Factor	Weighting, W_j dB	Weighting, W_j Phase degrees	Tolerance %	Tolerance dB	Tolerance $\Delta\varphi_0$ degrees
−10	0,1	0,1	0,062 38	−24,10	159,3	0,030 99	−30,18	159,8	+26/−100	+2/−∞	+∞/−∞
−9	0,125	0,125 9	0,098 57	−20,12	153,6	0,048 97	−26,20	154,2	+26/−100	+2/−∞	+∞/−∞
−8	0,16	0,158 5	0,155 1	−16,19	146,3	0,077 03	−22,27	147	+26/−100	+2/−∞	+∞/−∞
−7	0,2	0,199 5	0,241 5	−12,34	136,6	0,119 9	−18,42	137,6	+26/−100	+2/−∞	+∞/−∞
−6	0,25	0,251 2	0,366 9	−8,71	124,1	0,182 1	−14,79	125,3	+26/−100	+2/−∞	+∞/−∞
−5	0,315	0,316 2	0,53	−5,51	108,3	0,263	−11,60	109,9	+26/−21	+2/−2	+12/−12
−4	0,4	0,398 1	0,703 7	−3,05	90,06	0,348 9	−9,15	92,06	+26/−21	+2/−2	+12/−12
−3	0,5	0,501 2	0,843 4	−1,48	71,76	0,417 6	−7,58	74,31	+26/−21	+2/−2	+12/−12
−2	0,63	0,631	0,927 9	−0,65	55,78	0,458 5	−6,77	59,02	+12/−11	+1/−1	+6/−6
−1	0,8	0,794 3	0,969 3	−0,27	43,01	0,477 6	−6,42	47,18	+12/−11	+1/−1	+6/−6
0	1	1	0,987 4	−0,11	33,15	0,484 4	−6,30	38,57	+12/−11	+1/−1	+6/−6
1	1,25	1,259	0,994 9	−0,04	25,54	0,485 1	−6,28	32,71	+12/−11	+1/−1	+6/−6
2	1,6	1,585	0,998	−0,02	19,58	0,483 2	−6,32	29,31	+12/−11	+1/−1	+6/−6
3	2	1,995	0,999 2	−0,01	14,84	0,481 9	−6,34	28,42	+12/−11	+1/−1	+6/−6
4	2,5	2,512	0,999 7	0,00	10,97	0,488 9	−6,22	30,41	+12/−11	+1/−1	+6/−6
5	3,15	3,162	0,999 9	0,00	7,74	0,524 6	−5,60	35,14	+12/−11	+1/−1	+6/−6
6	4	3,981	0,999 9	0,00	4,941	0,625 1	−4,08	39,31	+12/−11	+1/−1	+6/−6
7	5	5,012	1	0,00	2,416	0,794 8	−1,99	36,78	+12/−11	+1/−1	+6/−6
8	6,3	6,31	1	0,00	0,024 4	0,947	−0,47	27,42	+12/−11	+1/−1	+6/−6
9	8	7,943	1	0,00	−2,366	1,016	0,14	17,07	+12/−11	+1/−1	+6/−6
10	10	10	0,999 9	0,00	−4,887	1,03	0,26	8,688	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,999 9	0,00	−7,679	1,026	0,22	2,043	+12/−11	+1/−1	+6/−6
12	16	15,85	0,999 7	0,00	−10,9	1,019	0,16	−3,729	+12/−11	+1/−1	+6/−6
13	20	19,95	0,999 2	−0,01	−14,75	1,012	0,10	−9,33	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	−19,47	1,006	0,06	−15,31	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,995	−0,04	−25,4	1	0,00	−22,16	+12/−11	+1/−1	+6/−6
16	40	39,81	0,987 7	−0,11	−32,97	0,991 1	−0,08	−30,43	+12/−11	+1/−1	+6/−6
17	50	50,12	0,969 9	−0,27	−42,78	0,972	−0,25	−40,78	+12/−11	+1/−1	+6/−6
18	63	63,1	0,929 1	−0,64	−55,49	0,930 4	−0,63	−53,9	+12/−11	+1/−1	+6/−6
19	80	79,43	0,845 7	−1,46	−71,41	0,846 5	−1,45	−70,15	+26/−21	+2/−2	+12/−12
20	100	100	0,707 1	−3,01	−89,68	0,707 5	−3,01	−88,68	+26/−21	+2/−2	+12/−12
21	125	125,9	0,533 6	−5,46	−107,9	0,533 8	−5,45	−107,1	+26/−21	+2/−2	+12/−12
22	160	158,5	0,369 9	−8,64	−123,8	0,37	−8,64	−123,2	+26/−100	+2/−∞	+∞/−∞
23	200	199,5	0,243 6	−12,27	−136,4	0,243 7	−12,26	−135,9	+26/−100	+2/−∞	+∞/−∞
24	250	251,2	0,156 5	−16,11	−146,1	0,156 5	−16,11	−145,7	+26/−100	+2/−∞	+∞/−∞
25	315	316,2	0,099 5	−20,04	−153,5	0,099 51	−20,04	−153,2	+26/−100	+2/−∞	+∞/−∞
26	400	398,1	0,062 97	−24,02	−159,2	0,062 97	−24,02	−158,9	+26/−100	+2/−∞	+∞/−∞

Key

X	frequency, Hz	1	band-limiting
Y	weighting factor	2	Weighting

Figure B.13 — Magnitude of frequency weighting W_j for vertical head vibration, *x*-axis recumbent person, based on ISO 2631-1
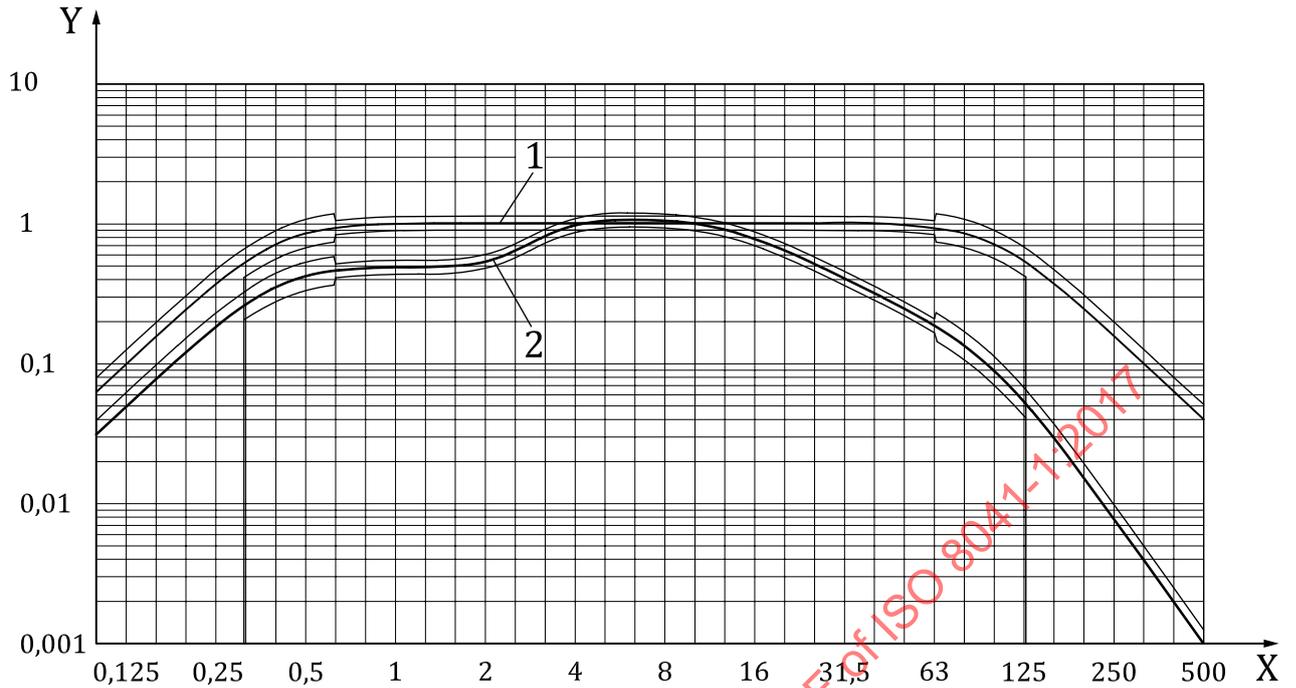

Key

X	frequency, Hz	1	band-limiting
Y	phase (degrees)	2	weighting

Figure B.14 — Phase of frequency weighting W_j for vertical head vibration, *x*-axis recumbent person, based on ISO 2631-1

Table B.8 — Frequency weighting W_k for vertical whole-body vibration, z-axis seated, standing or recumbent person, based on ISO 2631-1

n	Frequency Hz Nominal	True	Band-limiting Factor	dB	Phase degrees	Weighting, W_k Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ degrees
−10	0,1	0,1	0,062 38	−24,10	159,3	0,031 21	−30,11	159,8	+26/−100	+2/−∞	+∞/−∞
−9	0,125	0,125 9	0,098 57	−20,12	153,6	0,049 31	−26,14	154,3	+26/−100	+2/−∞	+∞/−∞
−8	0,16	0,158 5	0,155 1	−16,19	146,3	0,077 56	−22,21	147,1	+26/−100	+2/−∞	+∞/−∞
−7	0,2	0,199 5	0,241 5	−12,34	136,6	0,120 7	−18,37	137,7	+26/−100	+2/−∞	+∞/−∞
−6	0,25	0,251 2	0,366 9	−8,71	124,1	0,183 2	−14,74	125,4	+26/−100	+2/−∞	+∞/−∞
−5	0,315	0,316 2	0,53	−5,51	108,3	0,264 4	−11,55	109,9	+26/−21	+2/−2	+12/−12
−4	0,4	0,398 1	0,703 7	−3,05	90,06	0,350 4	−9,11	92,2	+26/−21	+2/−2	+12/−12
−3	0,5	0,501 2	0,843 4	−1,48	71,76	0,418 8	−7,56	74,54	+26/−21	+2/−2	+12/−12
−2	0,63	0,631	0,927 9	−0,65	55,78	0,458 8	−6,77	59,44	+12/−11	+1/−1	+6/−6
−1	0,8	0,794 3	0,969 3	−0,27	43,01	0,476 7	−6,44	47,96	+12/−11	+1/−1	+6/−6
0	1	1	0,987 4	−0,11	33,15	0,482 5	−6,33	40,06	+12/−11	+1/−1	+6/−6
1	1,25	1,259	0,994 9	−0,04	25,54	0,484 6	−6,29	35,55	+12/−11	+1/−1	+6/−6
2	1,6	1,585	0,998	−0,02	19,58	0,493 5	−6,13	34,48	+12/−11	+1/−1	+6/−6
3	2	1,995	0,999 2	−0,01	14,84	0,530 8	−5,50	36,45	+12/−11	+1/−1	+6/−6
4	2,5	2,512	0,999 7	0,00	10,97	0,633 5	−3,97	37,98	+12/−11	+1/−1	+6/−6
5	3,15	3,162	0,999 9	0,00	7,74	0,807 1	−1,86	32,73	+12/−11	+1/−1	+6/−6
6	4	3,981	0,999 9	0,00	4,941	0,964 8	−0,31	20,35	+12/−11	+1/−1	+6/−6
7	5	5,012	1	0,00	2,416	1,039	0,33	6,309	+12/−11	+1/−1	+6/−6
8	6,3	6,31	1	0,00	0,024 4	1,054	0,46	−6,841	+12/−11	+1/−1	+6/−6
9	8	7,943	1	0,00	−2,366	1,037	0,32	−19,73	+12/−11	+1/−1	+6/−6
10	10	10	0,999 9	0,00	−4,887	0,988 4	−0,10	−33,3	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,999 9	0,00	−7,679	0,898 9	−0,93	−47,62	+12/−11	+1/−1	+6/−6
12	16	15,85	0,999 7	0,00	−10,9	0,774 3	−2,22	−61,84	+12/−11	+1/−1	+6/−6
13	20	19,95	0,999 2	−0,01	−14,75	0,637 3	−3,91	−75,03	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	−19,47	0,510 3	−5,84	−87,02	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,995	−0,04	−25,4	0,403 1	−7,89	−98,35	+12/−11	+1/−1	+6/−6
16	40	39,81	0,987 7	−0,11	−32,97	0,316	−10,01	−109,9	+12/−11	+1/−1	+6/−6
17	50	50,12	0,969 9	−0,27	−42,78	0,245 1	−12,21	−122,7	+12/−11	+1/−1	+6/−6
18	63	63,1	0,929 1	−0,64	−55,49	0,185 7	−14,62	−137,6	+12/−11	+1/−1	+6/−6
19	80	79,43	0,845 7	−1,46	−71,41	0,133 9	−17,47	−155,2	+26/−21	+2/−2	+12/−12
20	100	100	0,707 1	−3,01	−89,68	0,088 73	−21,04	−174,8	+26/−21	+2/−2	+12/−12
21	125	125,9	0,533 6	−5,46	−107,9	0,053 11	−25,50	−194,1	+26/−21	+2/−2	+12/−12
22	160	158,5	0,369 9	−8,64	−123,8	0,029 22	−30,69	−210,7	+26/−100	+2/−∞	+∞/−∞
23	200	199,5	0,243 6	−12,27	−136,4	0,015 28	−36,32	−224	+26/−100	+2/−∞	+∞/−∞
24	250	251,2	0,156 5	−16,11	−146,1	0,007 795	−42,16	−234,2	+26/−100	+2/−∞	+∞/−∞
25	315	316,2	0,099 5	−20,04	−153,5	0,003 935	−48,10	−241,9	+26/−100	+2/−∞	+∞/−∞
26	400	398,1	0,062 97	−24,02	−159,2	0,001 978	−54,08	−247,9	+26/−100	+2/−∞	+∞/−∞

Key

X	frequency, Hz	1	band-limiting
Y	weighting factor	2	weighting

Figure B.15 — Magnitude of frequency weighting W_k for vertical whole-body vibration, *z*-axis seated, standing or recumbent person, based on ISO 2631-1

Key
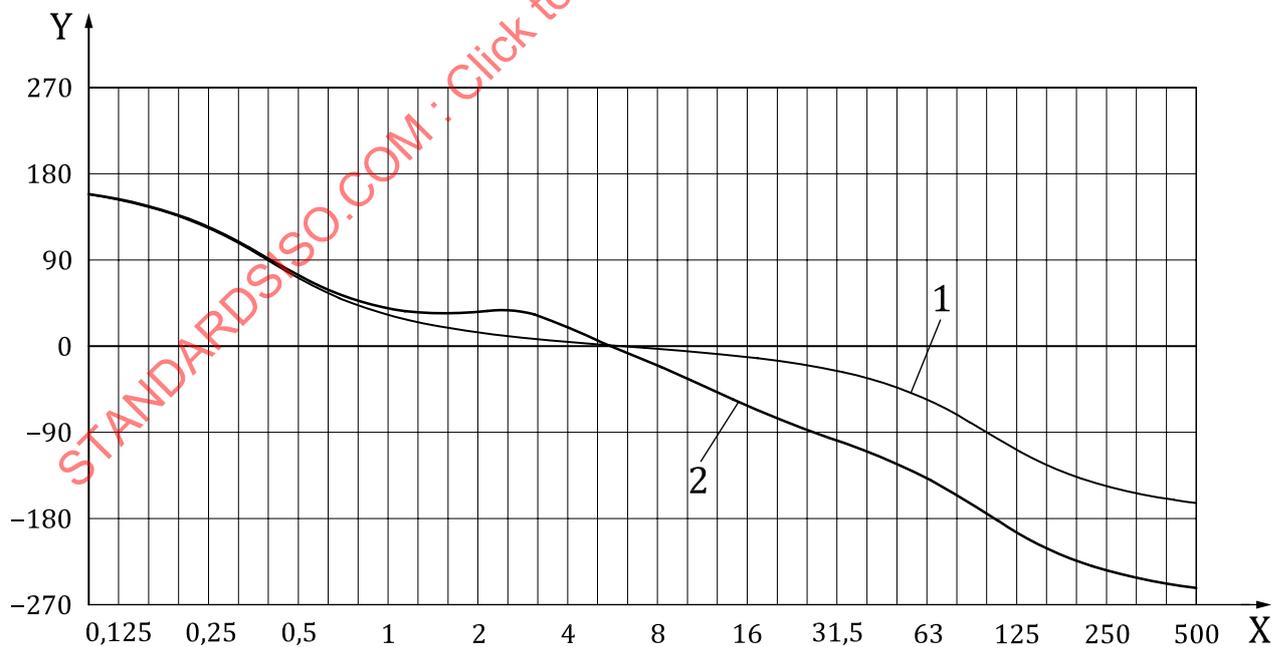
X	frequency, Hz	1	band-limiting
Y	phase (degrees)	2	weighting

Figure B.16 — Phase of frequency weighting W_k for vertical whole-body vibration, *z*-axis seated, standing or recumbent person, based on ISO 2631-1
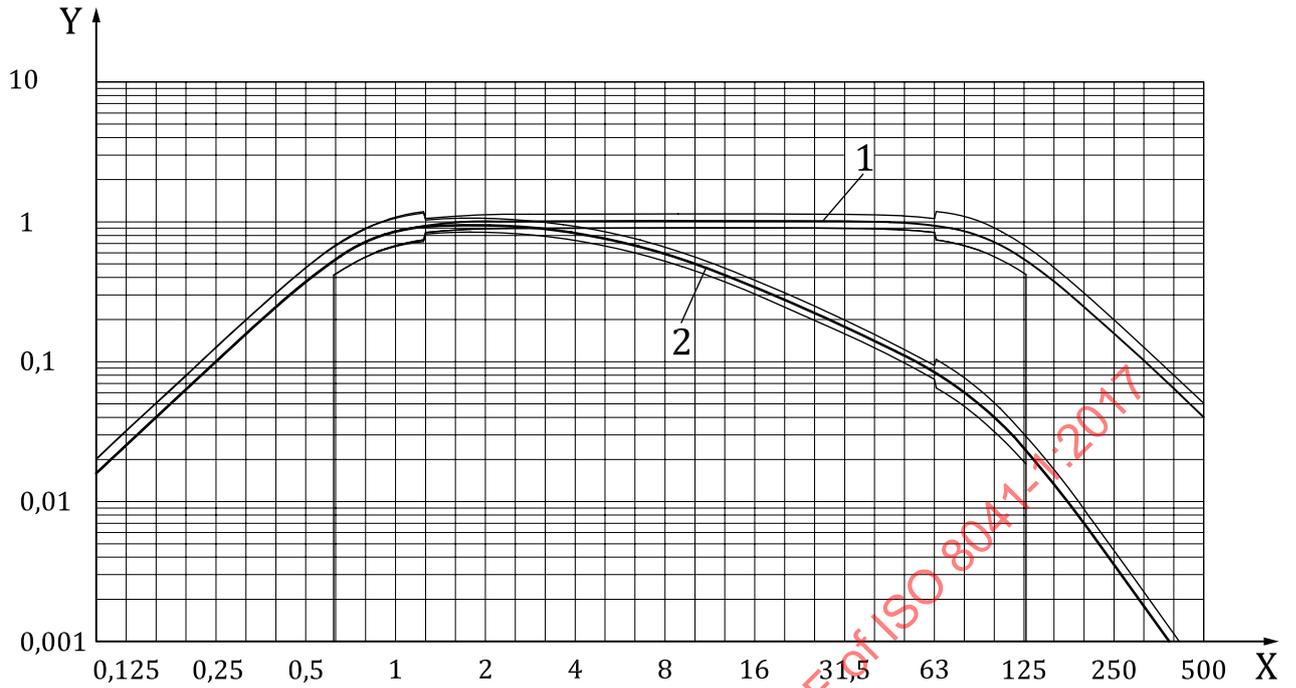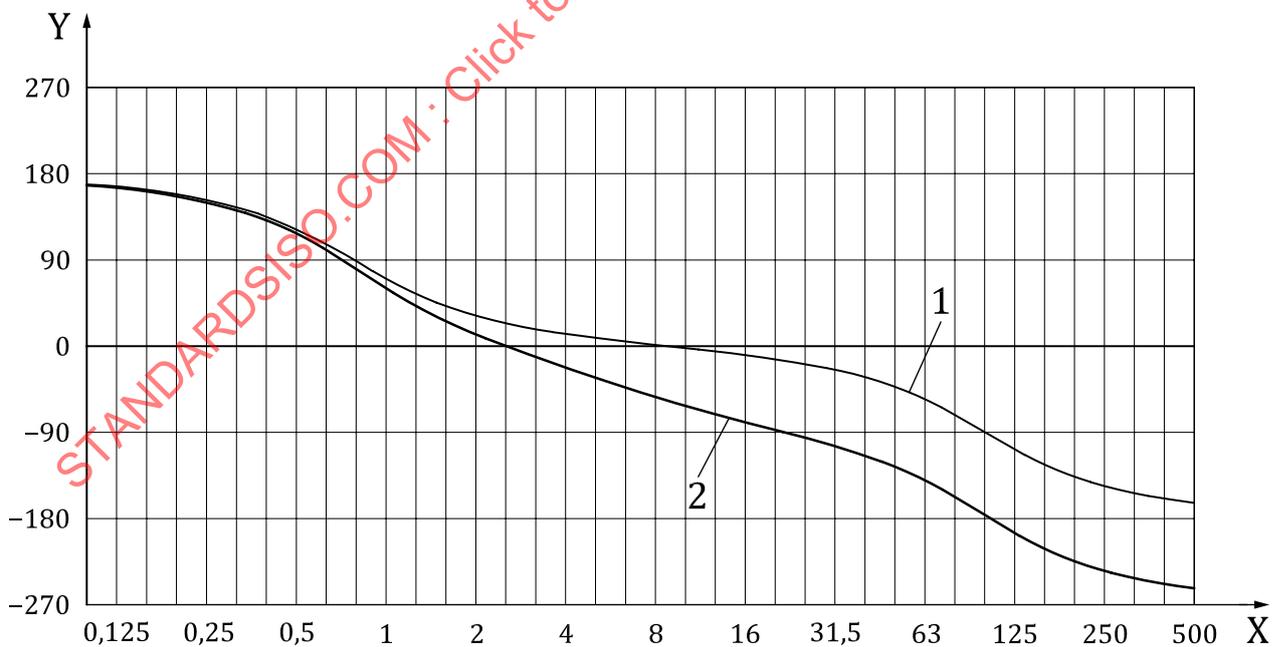
Table B.9 — Frequency weighting W_m for whole-body vibration in buildings, all directions, based on ISO 2631-2

n	Frequency Hz Nominal	True	Band-limiting Factor	dB	Phase degrees	Weighting, W_m Factor	dB	Phase degrees	Tolerance %	dB	$\Delta\varphi_0$ degrees
−10	0,1	0,1	0,015 85	−36,00	169,7	0,015 84	−36,00	168,7	+26/−100	+2/−∞	+∞/−∞
−9	0,125	0,125 9	0,025 11	−32,00	166,9	0,025 1	−32,00	165,7	+26/−100	+2/−∞	+∞/−∞
−8	0,16	0,158 5	0,039 78	−28,01	163,5	0,039 76	−28,01	161,9	+26/−100	+2/−∞	+∞/−∞
−7	0,2	0,199 5	0,062 97	−24,02	159,1	0,062 93	−24,02	157,1	+26/−100	+2/−∞	+∞/−∞
−6	0,25	0,251 2	0,099 5	−20,04	153,4	0,099 41	−20,05	150,8	+26/−100	+2/−∞	+∞/−∞
−5	0,315	0,316 2	0,156 5	−16,11	146	0,156 3	−16,12	142,8	+26/−100	+2/−∞	+∞/−∞
−4	0,4	0,398 1	0,243 6	−12,27	136,3	0,243	−12,29	132,2	+26/−100	+2/−∞	+∞/−∞
−3	0,5	0,501 2	0,369 9	−8,64	123,6	0,368 4	−8,67	118,6	+26/−100	+2/−∞	+∞/−∞
−2	0,63	0,631	0,533 6	−5,46	107,7	0,530 4	−5,51	101,3	+26/−21	+2/−2	+12/−12
−1	0,8	0,794 3	0,707 1	−3,01	89,36	0,700 3	−3,09	81,4	+26/−21	+2/−2	+12/−12
0	1	1	0,845 7	−1,46	71	0,832 9	−1,59	61,03	+26/−21	+2/−2	+12/−12
1	1,25	1,259	0,929 1	−0,64	54,98	0,907 1	−0,85	42,49	+12/−11	+1/−1	+6/−6
2	1,6	1,585	0,969 9	−0,27	42,14	0,934 2	−0,59	26,56	+12/−11	+1/−1	+6/−6
3	2	1,995	0,987 7	−0,11	32,17	0,931 9	−0,61	12,83	+12/−11	+1/−1	+6/−6
4	2,5	2,512	0,995	−0,04	24,39	0,910 1	−0,82	0,545 9	+12/−11	+1/−1	+6/−6
5	3,15	3,162	0,998	−0,02	18,2	0,872 1	−1,19	−10,89	+12/−11	+1/−1	+6/−6
6	4	3,981	0,999 2	−0,01	13,15	0,818 4	−1,74	−21,86	+12/−11	+1/−1	+6/−6
7	5	5,012	0,999 7	0,00	8,884	0,749 8	−2,50	−32,52	+12/−11	+1/−1	+6/−6
8	6,3	6,31	0,999 9	0,00	5,135	0,669 2	−3,49	−42,85	+12/−11	+1/−1	+6/−6
9	8	7,943	0,999 9	0,00	1,68	0,581 9	−4,70	−52,73	+12/−11	+1/−1	+6/−6
10	10	10	0,999 9	0,00	−1,68	0,494 1	−6,12	−62,07	+12/−11	+1/−1	+6/−6
11	12,5	12,59	0,999 9	0,00	−5,135	0,411 4	−7,71	−70,84	+12/−11	+1/−1	+6/−6
12	16	15,85	0,999 7	0,00	−8,884	0,337 5	−9,44	−79,15	+12/−11	+1/−1	+6/−6
13	20	19,95	0,999 2	−0,01	−13,15	0,273 8	−11,25	−87,25	+12/−11	+1/−1	+6/−6
14	25	25,12	0,998	−0,02	−18,2	0,220 3	−13,14	−95,45	+12/−11	+1/−1	+6/−6
15	31,5	31,62	0,995	−0,04	−24,39	0,176	−15,09	−104,2	+12/−11	+1/−1	+6/−6
16	40	39,81	0,987 7	−0,11	−32,17	0,139 6	−17,10	−114	+12/−11	+1/−1	+6/−6
17	50	50,12	0,969 9	−0,27	−42,14	0,109 3	−19,23	−125,7	+12/−11	+1/−1	+6/−6
18	63	63,1	0,929 1	−0,64	−54,98	0,083 36	−21,58	−139,8	+12/−11	+1/−1	+6/−6
19	80	79,43	0,845 7	−1,46	−71	0,060 36	−24,38	−156,9	+26/−21	+2/−2	+12/−12
20	100	100	0,707 1	−3,01	−89,36	0,040 13	−27,93	−176,1	+26/−21	+2/−2	+12/−12
21	125	125,9	0,533 6	−5,46	−107,7	0,024 07	−32,37	−195,1	+26/−21	+2/−2	+12/−12
22	160	158,5	0,369 9	−8,64	−123,6	0,013 26	−37,55	−211,5	+26/−100	+2/−∞	+∞/−∞
23	200	199,5	0,243 6	−12,27	−136,3	0,006 937	−43,18	−224,6	+26/−100	+2/−∞	+∞/−∞
24	250	251,2	0,156 5	−16,11	−146	0,003 541	−49,02	−234,7	+26/−100	+2/−∞	+∞/−∞
25	315	316,2	0,099 5	−20,04	−153,4	0,001 788	−54,95	−242,3	+26/−100	+2/−∞	+∞/−∞
26	400	398,1	0,062 97	−24,02	−159,1	0,000 899	−60,92	−248,3	+26/−100	+2/−∞	+∞/−∞

Key

X	frequency, Hz	1	band-limiting
Y	weighting factor	2	weighting

Figure B.17 — Magnitude of frequency weighting W_m for whole-body vibration in buildings, all directions, based on ISO 2631-2

Key

X	frequency, Hz	1	band-limiting
Y	phase (degrees)	2	weighting

Figure B.18 — Phase of frequency weighting W_m for whole-body vibration in buildings, all directions, based on ISO 2631-2

Annex C
(informative)

Realization of frequency weighting filters

C.1 Frequency domain

C.1.1 General

Any form of frequency analysis, analogue or digital, real-time, one-third-octave or FFT analysis, may be used to produce the frequency-weighted r.m.s. acceleration value, a_w, by summation of the squares of the weighted r.m.s. spectral components a_i, as shown by Formula (C.1):

$$a_w = \left[\sum_i \left(w_i a_i \right)^2 \right]^{1/2} \tag{C.1}$$

where w_i is the weighting factor at the i th frequency band.

NOTE   Frequency analysis cannot be used for VDV. Frequency analysis cannot be used for the running r.m.s. measurements required by this document due to the short (1 s) averaging time (or time constant) in relation to the inverse of the filter bandwidth.

C.1.2 One-third-octave-band analysis

For one-third-octave bands, use the centre frequencies stated in Tables B.1 to B.9. Use one-third-octave bands ranging from at least one octave above and one octave below the frequency limits (f_1 and f_2 in Table 3).

Multiply the vibration acceleration values by the appropriate frequency weighting factor calculated from 5.6 (given in Tables B.1 to B.9) before squaring and summation according to Formula (C.1).

C.1.3 Fast Fourier transform (FFT)

The weighted r.m.s. acceleration value, a_w, can be obtained from the FFT r.m.s. spectral components using Formula (C.1) or the power spectral density components, P_i, using Formula (C.2). However, the weighting factors, w, should be obtained using Formulae (1) to (5) rather than Tables B.1 to B.9.

$$a_w = \left[\sum_i w_i^2 P_i \Delta f \right]^{1/2} \tag{C.2}$$

In the summation process of power spectra, the spectral overlap caused by time windowing should be taken into account. For a broad-band spectrum, divide the frequency-weighted acceleration, a_w, calculated from Formula (C.2) by a factor that corresponds to the bandwidth of the equivalent ideal filter that passes the same power from a white noise source, see Table C.1.

Table C.1 — Time-window functions and their effective bandwidth

Time-window function[a]	Noise bandwidth factor	Application
Hanning	1,5	General purpose, non-stationary random processes
Flat-top	3,77	Periodic or sinusoidal signals (e.g. calibration)
[a] Other window functions are available and may be more suited to specific applications.		

The time-window noise bandwidth factor is normally taken into account within the power spectral function of FFT analysers.

The FFT frequency resolution should be less than 40 %, preferably 20 %, of the lowest frequency in the nominal frequency range. The sampling frequency should be at least 5 times the highest frequency in the nominal frequency range.

C.2 Time domain

C.2.1 General

The evaluation of vibration acceleration signals with respect to human response involves frequency weighting using one of the filters specified in 5.6. For linear time averages, the frequency weighting can be applied before the r.m.s. averaging of a time history, or after the computation of an r.m.s.-averaged spectrum; either method will give the same result. However, for parameters such as MTVV (see 3.1.2.3 and 3.1.2.4), the maximum value of a running r.m.s. signal is required (see Annex D). In this case, the frequency weighting needs to be applied to the time history before the integration since, by definition, the maximum of the *weighted* acceleration is determined.

The application of digital filtering in the time domain eliminates the need for analogue filters which otherwise would be costly and bulky, particularly in multi-channel systems.

C.2.2 Conversion of filters from frequency domain to time domain

While Laplace transforms are appropriate for the design of analogue filters in the frequency domain, z-transforms are generally used for digital filters to be realized in software. The transfer function of a digital filter can be represented by its z-transform $H(z)$. In the z-domain, the transform $Y(z)$ of the output from a digital filter relates to the transform $X(z)$ of the input signal through the product of Formula (C.3):

$$Y(z) = H(z) \cdot X(z) \tag{C.3}$$

$H(z)$ can be expressed as shown by Formula (C.4):

$$H(z) = \frac{\displaystyle\sum_{i=0}^{M} b_i z^{-i}}{1 + \displaystyle\sum_{i=1}^{N} a_i z^{-i}} \tag{C.4}$$

where

a_i and b_i are coefficients;

M and N are the number of zeros and poles, respectively.

The equivalent expression in the time domain is shown by Formula (C.5):

$$y(t_i) = \sum_{k=0}^{M} b_k x(t_{i-k}) - \sum_{j=1}^{N} a_j y(t_{i-j}) \tag{C.5}$$

where $x(t_i)$ and $y(t_i)$ are input and output signals, respectively, sampled at time t_i.

C.2.3   Calculation of filter coefficients

The filter coefficients a_i and b_i can be obtained by the bilinear transformation method or the impulse invariant method, see Reference [12]. The bilinear transformation method is the most appropriate for Butterworth filters like the high-pass and low-pass filters described in 5.6. The z-transforms of these 2-pole filters can be obtained from the Laplace format of the transfer functions in 5.6 by substituting the Laplace variable s, as shown by Formula (C.6):

$$s = \frac{z - 1}{T_s (z + 1)} \tag{C.6}$$

where T_s is the sampling interval.

A similar approach, or alternatively the impulse invariant method, may be used for the filters for a-v transition and upward step.

C.2.4   Application of the filters

The separate filters should be applied to the sampled time data in consecutive order using the infinite impulse response (IIR) filtering technique following Formula (C.5).

As an example, a MATLAB®[1] code is given in Figure C.1 for the W_k filter, utilizing the built-in function 'filter.m' and, from the signal analysis toolbox, 'butter.m' and 'bilinear.m'.

NOTE   The MATLAB®[1] code in Figure C.1 requires a sample rate of at least 9 times the upper frequency limit f_2 (in Table 3) to produce filters within the tolerances required by this document. The MATLAB®[1] code could be modified to allow lower sample rates, e.g. by use of the cotan transformation

$$s = \frac{2\pi f_{co}}{\tan(\pi f_{co} T_s)} \cdot \frac{z - 1}{z + 1}$$

where f_{co} is the cut-off frequency.

---

1)   MATLAB® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

```
function y = isofilwk(x,fs)

% ISOFILWK
% Filter ISO 8041 Wk, whole body, vertical direction
%           y = isofilwk(x,fs)
%           y output signal, acceleration
%           x input signal, acceleration
%           fs  sampling frequency, Hz
%           bilinear transformation algorithm is used

f1 = 0.4;
f2 = 100;
f3 = 12.5;
f4 = 12.5;
Q4 = 0.63;
f5 = 2.37;
Q5 = 0.91;
f6 = 3.35;
Q6 = 0.91;

% Note that in the function "butter" the variables Q1 and Q2 are
% effectively set to equal to 1/sqrt(2), therefore they don't need
% to be explicitly set here.


w3 = 2*pi*f3;
w4 = 2*pi*f4;
w5 = 2*pi*f5;
w6 = 2*pi*f6;

nyq = fs/2;                                % Nyquist frequency

% Determine parameters for band limiting high pass and low pass

[b1,a1] = butter(2,f1/nyq,'high');      % High pass
[b2,a2] = butter(2,f2/nyq);             % Low pass

% Determine parameters for a-v transition

B3 = [1/w3 1];
A3 = [1/w4/w4 1/Q4/w4 1];
[b3,a3] = bilinear(B3,A3,fs);

% Determine parameters for upward step

B4 = [1/w5/w5 1/Q5/w5 1]*w5*w5/w6/w6;
A4 = [1/w6/w6 1/Q6/w6 1];
[b4,a4] = bilinear(B4,A4,fs);

% Apply the function "filter" to input signal x (output signal y)

y = filter(b2,a2,x);   % Apply low-pass band limiting
y = filter(b1,a1,y);   % Apply high-pass band limiting
y = filter(b3,a3,y);   % Apply a-v transition
y = filter(b4,a4,y);   % Apply upward step
```

Figure C.1 — Example code for applying the frequency weighting W_k to a time signal

Annex D
(informative)

Running r.m.s. time averaging

D.1 Linear running r.m.s. time averaging

Linear running r.m.s. acceleration evaluation, see 3.1.2.3, is achievable in practice with digital signal processing which allows inexpensive storage of a large amount of data (signal samples), see Figure D.1.
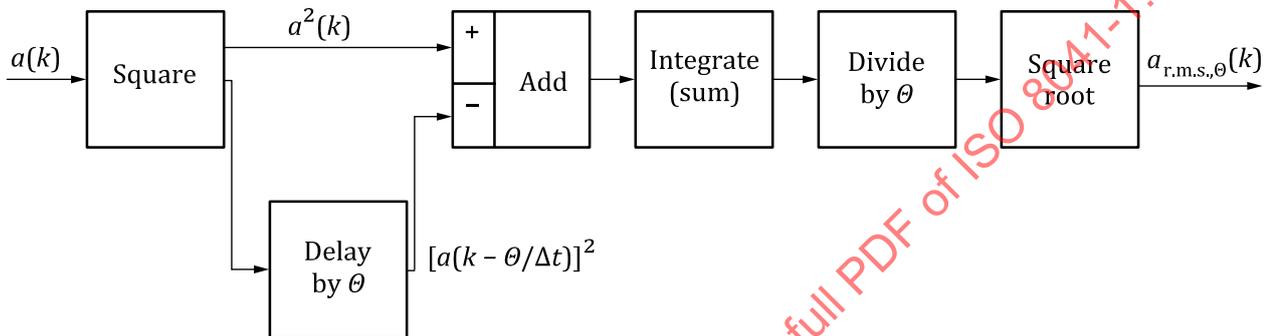

Key

k sample number

Δt sample period

q integration time

Figure D.1 — Method for achieving linear r.m.s. averaging

D.2 Exponential running r.m.s. time averaging

Exponential running r.m.s. evaluation, see 3.1.2.4, has been used for a long time in the field of sound measurement and human-vibration measurement. First, it was standardized for sound level meters as the time weightings "slow" (time constant of 1 s) and "fast" (time constant of 0,125 s), then later for human-vibration meters also. Exponential time weighting is also known as "exponential averaging", "exponentially time-weighted r.m.s." or as "running r.m.s. with exponential time window". Figure D.2 shows how exponential running r.m.s. acceleration averaging can be achieved.
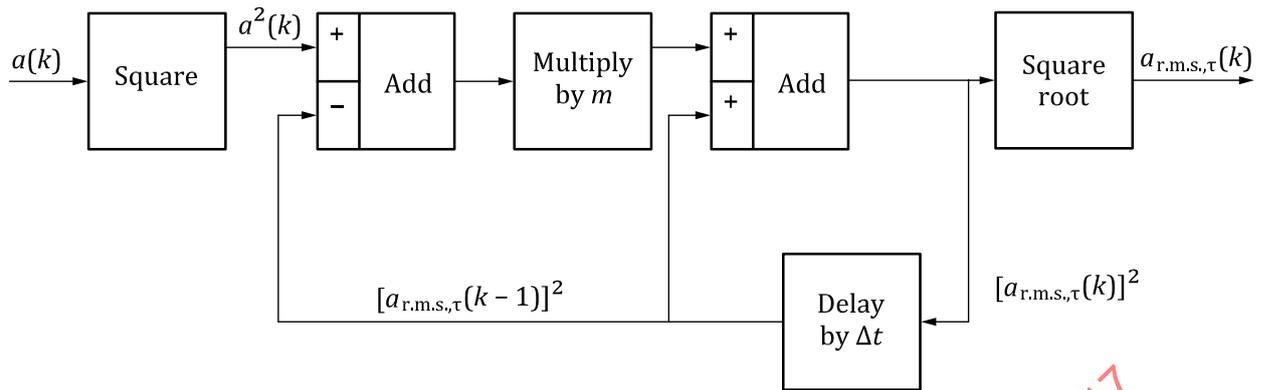
**Key**

m $1 - e^{-\Delta t/t}$

t time constant

Figure D.2 — Method for achieving exponential r.m.s. averaging

D.3   Comparison of linear and exponential running r.m.s. time averaging

The r.m.s. average results given by the formulae in 3.1.2.3 and 3.1.2.4, can differ considerably. There are two main equivalence criteria that may be used to compare the effects of the methods, depending on the application and the type of signal, as follows.

a) **Equivalence criterion 1** (Figure D.3): For optimum correspondence with respect to maximum values of the running r.m.s. (i.e. MTVV) of impulsive signals (shocks), the integration time of the linear averaging should be nearly equal to the time constant of the exponential averaging. However, considerable differences can occur depending on the length and the waveform of the shock.


Key
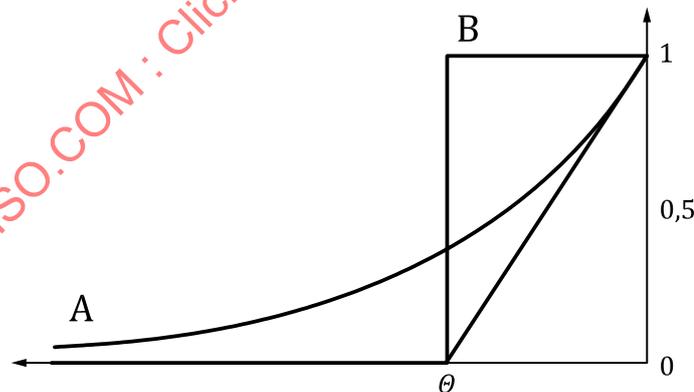
A   exponential

B   linear

Figure D.3 — Equivalent time windows for nearly equal maximum running r.m.s. of impulsive signals

b) **Equivalence criterion 2** (Figure D.4): For optimum correspondence with respect to variance or to the coverage probability (or other statistical parameters) of the running r.m.s. of random signals, the integration time of the linear averaging should be twice the time constant of the exponential averaging. The same is true for the ripple in the case of pulse trains or periodic signals. However, with the latter and linear averaging, severe interference effects can occur depending on the averaging time relative to the cycle duration.

Key
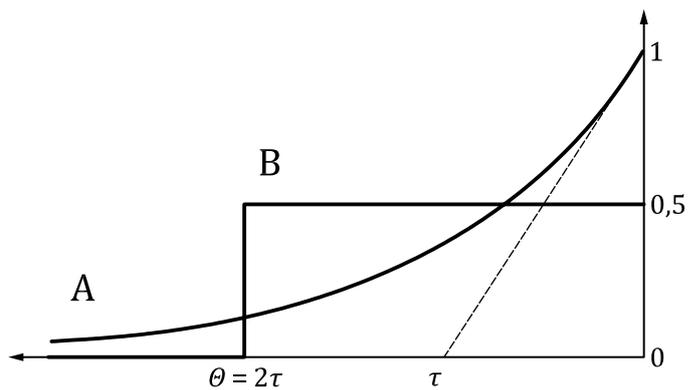
A   exponential

B   linear

Figure D.4 — Equivalent time windows for nearly equal r.m.s. average or other statistical parameters

Annex E
(informative)

Vibration transducer characteristics

E.1 General

The choice of vibration transducer for human response to vibration measurement depends on many factors, for example:

— the general application, i.e. hand-arm, whole-body or low-frequency whole-body vibration;

— the specific application, e.g. measurements for health, comfort or perception purposes;

— environmental conditions, e.g. hot, humid or dusty environments;

— fixing constraints, e.g. fixing to lightweight structures, limited available space.

Where indicated in this annex, typical specifications are given for vibration transducers used for assessments of typical health effects. Other applications can require less demanding specifications, some can require more strict specifications.

NOTE   The description in this document is based on vibration acceleration as the quantity detected by the vibration transducer. Transducers measuring other vibration quantities, such as vibration velocity, can be used provided that the overall requirements are satisfied. The requirements for the tests by electrical signals might need to be modified accordingly.

E.2 Specifications

Recommended minimum specifications for vibration transducers are given in Table E.1. However, these specifications might not be applicable in all cases.

Table E.1 — Vibration transducer specifications

| Characteristic | Specific requirements, influence on uncertainty of measurement | Hand-arm vibration | Whole-body vibration | | Low-frequency whole-body vibration |
			Vehicles	Buildings	
Maximum total mass (of all vibration transducers and mounting system)	< 10 % of the effective mass of the vibrating structure	30 g	450 g on seat, 50 g elsewhere	1 kg	1 kg
Maximum vibration transducer mass		5 g	50 g	200 g	200 g
Maximum total size (of all vibration transducers and mounting system)	Unobtrusive, minimum interference with normal activities	25 mm cube	<u>On seat</u>: 300 mm diameter × 12 mm height (semi-rigid disc, see F.2) <u>Other loca-tions</u>:30 mm cube	200 mm × 200 mm × 50 mm height	200 mm × 200 mm × 100 mm height
Maximum mounting height	Where a vibration transducer is mounted above a vibrating surface (e.g. on a mounting block) but is aligned, measure the vibration parallel to that surface. Then the distance between the measurement axis of the vibration transducer and the mounting surface should be as small as possible. This will minimize the amplification of rotational acceleration components.	10 mm	10 mm	25 mm	50 mm
Temperature range		−10 °C to 50 °C	−10 °C to 50 °C	−10 °C to 50 °C	−10 °C to 50 °C
Electromagnetic fields (30 mT at 50 Hz or 60 Hz)		< 30 m/s^2/T	< 5 m/s^2/T	< 2 m/s^2/T	< 2 m/s^2/T
Acoustic sensitivity		< 0,05 m/s^2/ kPa	< 0,01 m/s^2/ kPa	< 0,01 m/s^2/ kPa	< 0,01 m/s^2/ kPa
Transverse sensitivity	Sensitivity of single-axis trans-ducers to vibration along axes at 90° to the principal axis, see Notes 1 and 2	< 5 %	< 5 %	< 5 %	< 5 %
NOTE 1 The transverse sensitivity is axis and possibly frequency and amplitude dependent; it is usually given as a single value representing the worst-case situation.					
NOTE 2 Where multi-axis (3 or 6 axes) measurements are made, the measurement results may be corrected for the effect of the transverse sensitivities of the vibration transducers, provided that appropriate detailed information is available.					
NOTE 3 Since high-frequency components in shocks of short duration can excite the accelerometer at its resonance frequency it is useful to use mechanical (low-pass) filters. This also prevents the sensing element of the accelerometer from damage and limits the uncertainty of measurement. The transducer resonance frequency f_n is likely not to be excited if for the shock duration T the following relation is satisfied: $T \geq 5/f_n$.					
NOTE 4 A different transducer can be required for high-shock vibration than for lower vibration.					

Table E.1 *(continued)*

| Characteristic | Specific requirements, influence on uncertainty of measurement | Hand-arm vibration | Whole-body vibration | | Low-frequency whole-body vibration |
			Vehicles	Buildings	
Maximum unweighted shock acceleration	The vibration transducer needs to be capable of withstanding the high unweighted shock accelerations to which it can be exposed, while providing accurate information within the measurement frequency range, see Notes 3 and 4	30 000 m/s^2 (can be up to 50 000 m/s^2 for pneumatic hammers)	1 000 m/s^2	500 m/s^2	500 m/s^2
Phase response	Important for measurements of non-r.m.s. parameters: VDV, MTVV and peak	Within the characteristic phase deviation requirements for the vibration instrument (no rapid changes in phase with frequency within the nominal frequency range)			
Minimum resonance frequency	Should be greater than approximately ten times the nominal upper frequency limit	10 kHz	800 Hz	800 Hz	5 Hz
Minimum enclosure specification	Suggested enclosure specifications to prevent ingress of water and dust. Other specifications can be required for certain applications, e.g. laboratory-based measurements might not need any IP specification while measurements in explosive atmospheres can need higher IP ratings	IP 55	IP 55	None	IP 55

NOTE 1   The transverse sensitivity is axis and possibly frequency and amplitude dependent; it is usually given as a single value representing the worst-case situation.

NOTE 2   Where multi-axis (3 or 6 axes) measurements are made, the measurement results may be corrected for the effect of the transverse sensitivities of the vibration transducers, provided that appropriate detailed information is available.

NOTE 3   Since high-frequency components in shocks of short duration can excite the accelerometer at its resonance frequency it is useful to use mechanical (low-pass) filters. This also prevents the sensing element of the accelerometer from damage and limits the uncertainty of measurement. The transducer resonance frequency f_n is likely not to be excited if for the shock duration T the following relation is satisfied: $T \geq 5/f_n$.

NOTE 4   A different transducer can be required for high-shock vibration than for lower vibration.

Annex F
(informative)

Tests for mounting systems

F.1   Hand-arm measurement

F.1.1   General

Mounting systems for hand-arm vibration measurement shall provide a lightweight, small and rigid system to ensure that the output from the vibration transducers accurately reproduces the vibration acceleration on the vibrating surface.

This annex provides an optional basic test procedure for single-axis and triaxial mounting systems.

F.1.2   Test procedure

Tests shall be carried out on accelerometers mounted as shown in Figure F.1. The reference vibration transducer shall satisfy the accelerometer requirements of this document. The test mounting system and test accelerometer shall be those specified for use with the instrumentation being evaluated against this document.

The test handles shall be rigid 25 mm diameter cylinders of length 125 mm. The input vibration shall be applied to the handle, in the direction indicated in Figure F.1. The handle may be supported at any point or points provided that the test mounting system is not affected and, where appropriate, the mounting system may be held in place by hand. All measurements shall be made along the axis of the input vibration.

Where a mounting is designed to be hand-held, it shall be tested hand-held, using a loose and tight grip force. If any additional fixing is specified in the instrument documentation, this shall be used for these tests.

Ideally the grip force should be monitored and controlled throughout the measurement. Grip forces that change during measurement can affect the apparent response of the mounting system.

Apply a single-axis white noise input vibration spectrum in the axis as shown in Figure F.1. The minimum frequency range of the spectrum shall be from 31,5 Hz to 1 250 Hz with an overall W_h weighted r.m.s. value of 10 m/s^2. The tolerance on the white noise spectrum is ± 20 %, as measured at the reference point on the test handle.

Carry out dual-channel analysis, with a frequency increment not greater than 8 Hz, covering the whole frequency range, of the outputs from the reference and mounted test accelerometers.

Make three repeat measurements, over periods of not less than 30 s. Between each measurement, remove and refit the mounting system.

The frequency response function between the reference vibration transducer and the mounted test vibration transducer shall be 1,0 with a tolerance of ± 15 % at all frequencies. The coherence of the frequency response function shall be better than 0,8 at all frequencies from 31,5 Hz to 1 250 Hz.

If dual-channel analysis is not available, make a simultaneous measurement of the spectrum from the mounted test and reference vibration transducers. At all frequencies from 31,5 Hz to 1 250 Hz, the test accelerometer spectrum shall be within 15 % of that of the reference vibration transducer.