INTERNATIONAL STANDARD

ISO 8041

Second edition
2005-04-01

Human response to vibration — Measuring instrumentation

Réponse des individus aux vibrations — Appareillage de mesure

Reference number
ISO 8041:2005(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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

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

ISO 8041 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

This second edition cancels and replaces the first edition (ISO 8041:1990), which has been technically revised, and incorporates its Amendment, ISO 8041:1990/Amd.1:1999, and Technical Corrigendum ISO 8041:1990/Cor.1:1993.

The reasons for the main changes introduced in this edition are as follows:

— to improve the specifications for human response to vibration measuring instrumentation;

— to incorporate into one document the specifications introduced by the 1999 amendment to ISO 8041:1990, which themselves were required following the introduction of new frequency weightings in ISO 2631-1:1997;

— to recognise changes in the frequency weighting specification introduced in ISO 5349-1:2001 that allows frequencies outside the one-third octaves from 6,3 Hz to 1250 Hz to be excluded from the weighted acceleration calculation (this is achieved by changing the frequencies at which the tolerance is extended to –100 % to be the lower boundary of the 6,3 Hz one-third-octave bands and the upper boundary of the 1 250 Hz one-third-octave band);

— to introduce allowances for the uncertainties of testing the conformance of the human vibration measuring instruments;

— to introduce a hierarchy of testing requirements (pattern evaluation, periodic verification and *in-situ* check) with tests defined according to the needs of this hierarchy;

— to recognise the needs for the specification and testing of new parameters such as maximum transient vibration value (MTVV) and vibration dose value (VDV);

— to recognise the need to test multi-axis instrumentation and to test combined results from these multi-axis inputs;

— to introduce informative tests for mounting methods.

Human response to vibration — Measuring instrumentation

1 Scope

This International Standard 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, periodic verification and *in-situ* checks, and the specification of vibration calibrators for *in-situ* checks.

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

Vibration instruments specified in this International Standard are intended to measure vibrations for one or more applications, such as

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

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

— 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 International Standard:

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

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

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

ISO 2041, *Vibration and shock — Vocabulary*

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, *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*

IEC 61000-4-2:2001, *Electromagnetic compatibility (EMC) — Part 4-2: Testing and measurement techniques — Electrostatic discharge immunity test*

IEC 61000-4-3:2002, *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 61000-6-2:1999, *Electromagnetic compatibility (EMC) — Part 6-2: Generic standards — Immunity for industrial environments*

CISPR 22:2003, *Information technology equipment — Radio disturbance characteristics — Limits and methods of measurement*

GUM, *Guide to the expression of uncertainty in measurement*. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1993

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1
vibration acceleration
component of acceleration, where the axis of measurement is specified by application standards

3.1.2
band-limiting frequency weighting
component of a frequency weighting defined by the high and low pass band-limiting filters

3.1.3
band-limited frequency range
frequency range defined by the band-limited component of a frequency weighting

3.1.4
nominal frequency range
frequency range of interest, as defined in the relevant measurement standard

3.1.5 Frequency-weighted values

3.1.5.1
time-averaged weighted acceleration value
frequency-weighted 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:

$$a_\mathrm{w} = \left(\frac{1}{T} \int_0^T a_\mathrm{w}^2 (\xi) \, \mathrm{d}\xi \right)^{1/2} \tag{1}$$

where

$a_w(\xi)$ is the translational or rotational, weighted vibration acceleration in 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

3.1.5.2
time-averaged weighted acceleration level
frequency-weighted r.m.s. vibration acceleration level expressed in decibels, as defined by

$$L_w = 20 \lg \frac{a_w}{a_0} \text{ dB} \tag{2}$$

where

a_w is defined in 3.1.5.1;

a_0 is the reference acceleration (defined as 10^{-6} m/s^2 in ISO 1683)

3.1.5.3
running r.m.s. acceleration value
frequency-weighted running r.m.s. vibration acceleration, in metres per second squared, defined by the expression

$$a_{w,\theta}(t) = \left(\frac{1}{\theta} \int_{t-\theta}^{t} a_w^2(\xi) \mathrm{d}\xi \right)^{1/2} \tag{3}$$

where

$a_w(\xi)$ is the frequency-weighted instantaneous vibration acceleration at time ξ, in metres per second squared;

θ is the integration time of the measurement;

t is the instantaneous time

NOTE 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:

$$a_{w,\tau}(t) = \left(\frac{1}{\tau} \int_{-\infty}^{t} a_w^2(\xi) \exp\left(\frac{\xi - t}{\tau} \right) \mathrm{d}\xi \right)^{1/2} \tag{4}$$

where τ is the time constant.

3.1.5.4
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

3.1.5.5
motion sickness dose value
MSDV
integral of the squared weighted instantaneous vibration acceleration $a_w(t)$ in m/s^{1,5} as defined by the expression:

$$\mathrm{MSDV} = \left(\int_0^{\Phi} a_{\mathrm{w}}^2 (\xi) \mathrm{d}\xi \right)^{1/2} \tag{5}$$

where Φ is the total period during which motion could occur

NOTE 1 The motion sickness dose value may be obtained from the frequency weighted r.m.s. vibration acceleration through multiplication by $\Phi^{1/2}$.

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

3.1.5.6
vibration dose value
VDV
integral of the fourth power of the weighted instantaneous vibration acceleration $a_{\mathrm{w}}(t)$ in m/s^{1,75} as defined by the expression

$$\mathrm{VDV} = \left(\int_0^{\Phi} a_{\mathrm{w}}^4 (\xi) \mathrm{d}\xi \right)^{1/4} \tag{6}$$

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

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

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

3.1.5.7
vibration total value
combined vibration from three axes of translational vibration, as defined by the expression

$$a_{\mathrm{w}v} = \sqrt{k_x a_{\mathrm{w}x}^2 + k_y a_{\mathrm{w}y}^2 + k_z a_{\mathrm{w}z}^2} \tag{7}$$

where

$a_{\mathrm{w}x}$, $a_{\mathrm{w}y}$ and $a_{\mathrm{w}z}$ are the 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

3.1.5.8
peak vibration value
maximum modulus of the instantaneous (positive and negative) peak values of the frequency-weighted acceleration

3.1.5.9
crest factor
parameter for a measurement period, given by the peak vibration value divided by the r.m.s. acceleration value, with both values having the same frequency weighting

3.1.6
linear operating range
on each measurement range, the range between lower and upper boundaries over which the linearity errors are within the applicable tolerance limits specified in this International Standard

3.1.7
overload
condition that occurs when the upper boundary of the linear operating range is exceeded

3.1.8
under-range
condition that occurs when the vibration value is below the lower boundary of the linear operating range

3.1.9
reference measurement range
level range specified for testing the characteristics of the vibration instrumentation

NOTE This range is that used for measuring the reference vibration.

3.1.10
reference vibration signal
sinusoidal vibration signal, the magnitude and frequency of which is specified in this International Standard for testing the electromechanical performance of a human-vibration meter

NOTE Different reference vibration signals are specified according to the application of the instrumentation.

3.1.11
calibration check frequency
frequency specified for providing a check of the vibration sensitivity of the instrument

3.1.12
tone burst
one or more complete cycles of a sinusoidal signal that start and end at a zero crossing of the waveform

3.1.13
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

3.1.14
vibration measuring instrumentation
combination of a vibration transducer, signal processor and display, being any single instrument, or a collection of instruments, which is capable of measuring parameters relating to human response to vibration

NOTE See Figure 1.

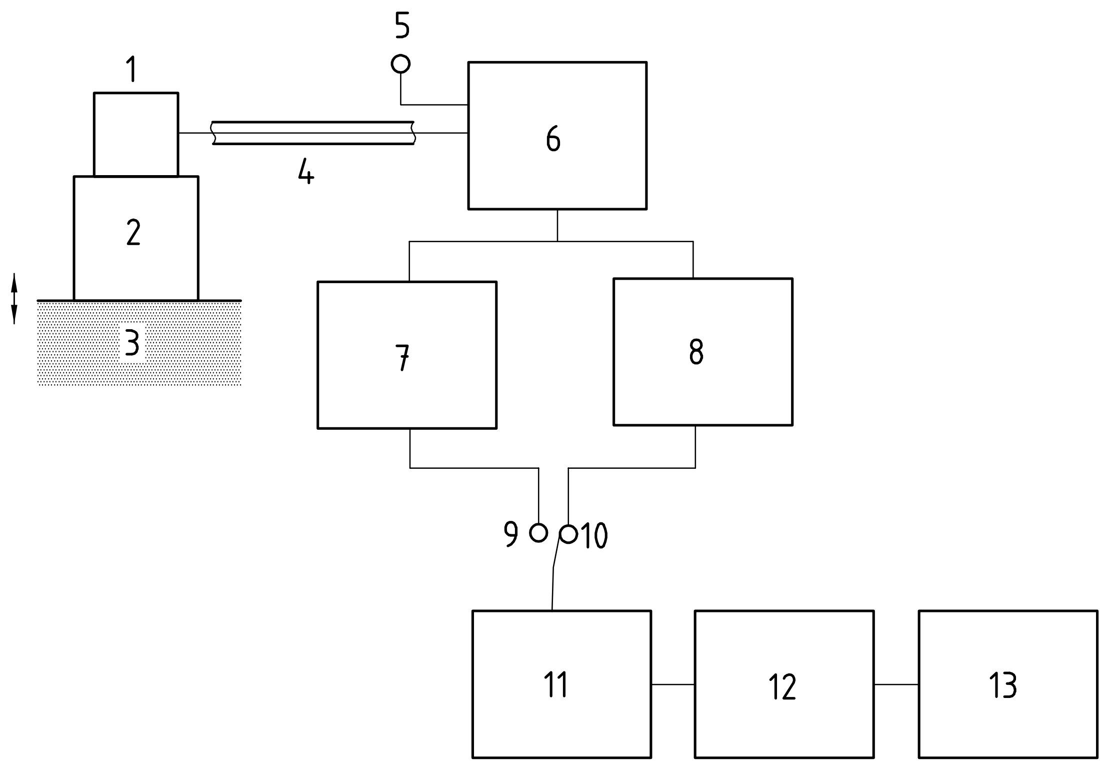
3.1.15
instrument documentation
instruction manual, operating procedure, or other documentation provided for the use of users of the vibration measurement instrument

3.2 Symbols

For the purposes of this document, the following symbols and abbreviated terms are used:

a_{w}	time-averaged frequency-weighted single-axis vibration acceleration
$a_{\mathrm{w}}(t)$, $a_{\mathrm{w}}(\xi)$	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

t or ξ	instantaneous time
T	measurement duration
s	variable of the Laplace transform
W_x	frequency weighting x
Φ	exposure duration
$\Delta\varphi$	phase error
τ	exponential averaging time constant
θ	linear averaging time
MTVV	maximum transient vibration value
MSDV	motion sickness dose value
VDV	vibration dose value

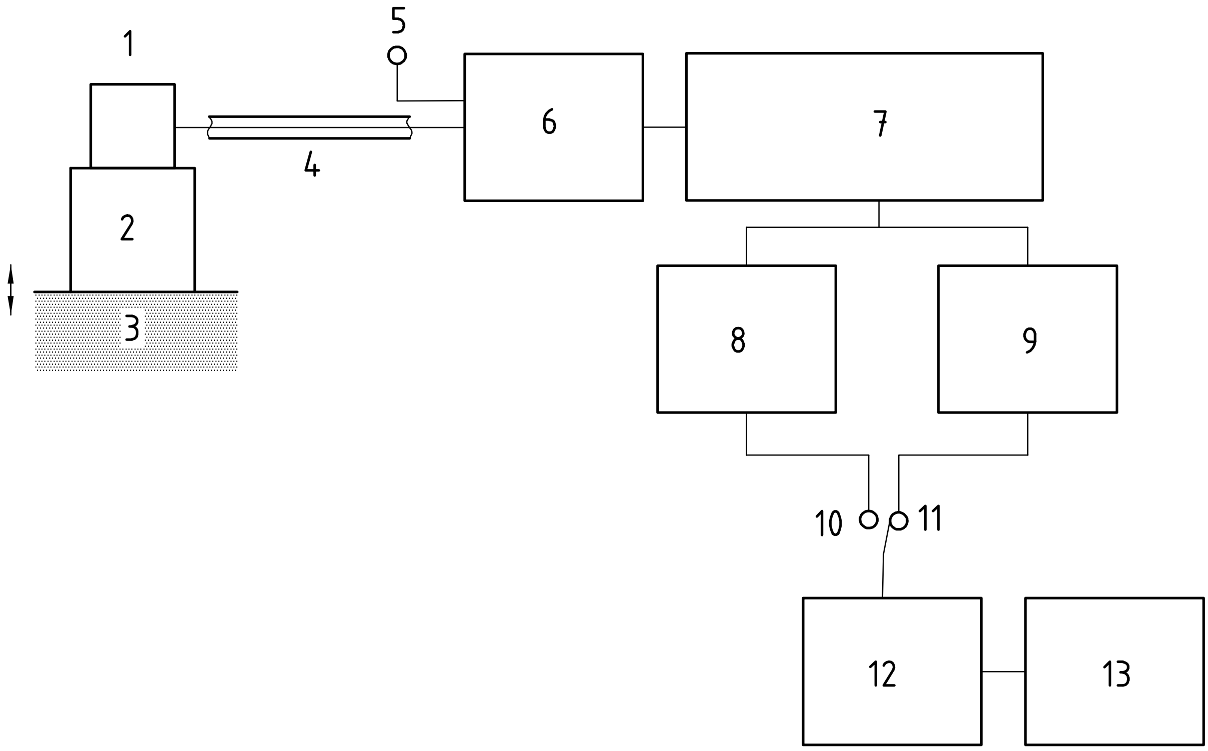


Key

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

a) Time-domain signal processing

Figure 1 — Overview of the basic functional path output of a vibration measurement instrument or measurement system



Key

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

b) **Frequency-domain signal processing** (not applicable to VDV processing)

Figure 1 (*continued*)

4 Reference environmental conditions

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

— air temperature: 23 °C;

— 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,

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

— measurement duration.

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 International Standard. 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 frequencies and values are given in Table 1.

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 International Standard 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 may provide an input test point, or a dummy vibration transducer of specified electrical impedance, 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.

Table 1 — Reference vibration values and frequencies

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

The tolerance limits given in this International Standard include the associated expanded uncertainties of measurement, calculated for a coverage factor of 2, corresponding to a level of confidence of approximately 95 %, in accordance with guidance given in the GUM.

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 the 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, Equation (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 International Standard, 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 1 % of the indicated value, or better.

If an instrument only has an analog, or simulated analog, display device that provides a continuous indication, the display shall be a logarithmic display of the vibration value. The range of the analog 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 International Standard 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 may 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 a.c. 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 peak-to-peak,
- 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 vibration field calibrator as a means to check and maintain the mechanical sensitivity of the human-vibration instrument. The vibration field 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 International Standard by application of the specified 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 International Standard 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 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 Equations (8) to (12) 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
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, Table A.1 of ISO 2631-4:2001 rounds the value of parameter Q_1 to 2 decimal places. The parameter specified here is the exact value.

NOTE 2 For weighting W_h, Table A.1 of ISO 5349-1:2001 rounds the values of parameters f_1, f_2, f_3 and f_4 to 5 significant figures and parameter Q_1 to 2 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 Equations (8) to (12) 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 follows:

a) High pass

$$H_\mathrm{h}(s) = \frac{1}{1 + \frac{\omega_1}{Q_1 s} + \left(\frac{\omega_1}{s}\right)^2} \tag{8}$$

b) Low pass

$$H_\mathrm{l}(s) = \frac{1}{1 + \frac{s}{Q_2 \omega_2} + \left(\frac{s}{\omega_2}\right)^2} \tag{9}$$

The product $H_\mathrm{h}(s) \times H_\mathrm{l}(s)$ 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:

$$H_\mathrm{t}(s) = \frac{\left(1 + \frac{s}{\omega_3}\right) K}{1 + \frac{s}{Q_4 \omega_4} + \left(\frac{s}{\omega_4}\right)^2} \tag{10}$$

NOTE $H_\mathrm{t}(s) = 1$ 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:

$$H_\mathrm{s}(s) = \frac{1 + \frac{s}{Q_5 \omega_5} + \left(\frac{s}{\omega_5}\right)^2}{1 + \frac{s}{Q_6 \omega_6} + \left(\frac{s}{\omega_6}\right)^2} \left(\frac{\omega_5}{\omega_6}\right)^2 \tag{11}$$

NOTE $H_\mathrm{s}(s) = 1$ 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 a product of band-limiting, a-v transition and upward-step filters, i.e.:

$$H(s) = H_\mathrm{h}(s) \times H_\mathrm{l}(s) \times H_\mathrm{t}(s) \times H_\mathrm{s}(s) \tag{12}$$

The most common interpretation of these equations 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 may 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 Equations (8) to (12) 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 Equations (8) to (12) may be realised by combinations of simple analog filters. Annex C provides example of how the frequency weightings may be realised digitally in the time and frequency domains.

5.6.6 Tolerances

The tolerances on the frequency weightings shall be as 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 shall 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 Equations (8) to (12). 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

$$\Delta\varphi_0 = \left| \frac{f_n \Delta\varphi_{n+1} - f_{n+1}\Delta\varphi_n}{f_{n+1} - f_n} \right| \tag{13}$$

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

Weighting	**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], $\Delta\varphi_0$
$f \leqslant f_{t1}$	+26 %, −100 %	$\pm\infty$
$f_{t1} < f < f_{t2}$	+26 %, −21 %	±12°
$f_{t2} \leqslant f \leqslant f_{t3}$	+12 %, −11 %	±6°
$f_{t3} < f < f_{t4}$	+26 %, −21 %	±12°
$f_{t4} \leqslant f$	+26 %, −100 %	$\pm\infty$

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 may 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.

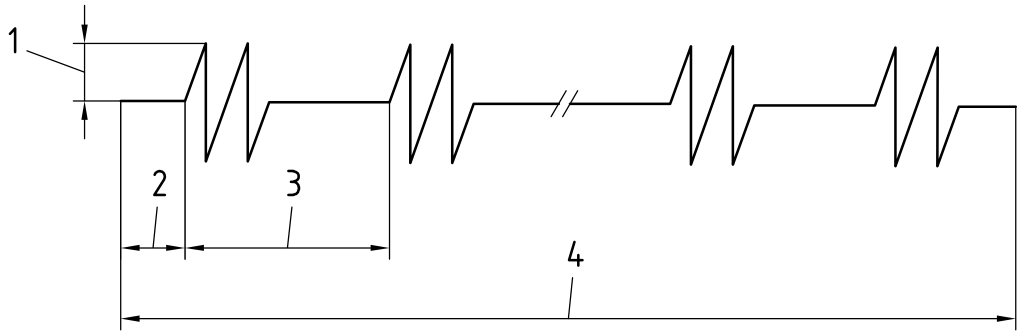
5.9 Signal-burst response

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

Table 6 — Saw-tooth signal burst test signal characteristics

Application	**Weighting**	**Angular frequency** rad/s	**Start time** s	**Number of cycles**	**Repeat time** s	**Duration** s
Hand-arm	W_h	500 (79,58 Hz)	0,2	1, 2, 4, 8 and 16	2	12
Whole-body	W_b, W_c, W_d, W_e, W_j, W_k, W_m	100 (15,915 Hz)	1		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 instruments

Weighting	**Number of saw-tooth cycles per burst**	**r.m.s.**	**Tolerance** %
Band limiting	1	0,0448	10
	2	0,0633	10
	4	0,0895	10
	8	0,127	10
	16	0,179	10
	Continuous	0,565	10
W_h	1	0,0103	10
	2	0,0133	10
	4	0,0168	10
	8	0,0224	10
	16	0,0309	10
	Continuous	0,0946	10

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

Weighting	Number of saw-tooth cycles per burst	r.m.s.	Tolerance %	VDV	Tolerance %	MTVV linear	Tolerance %	MTVV exp	Tolerance %
Band limiting	1	0,0433	10	0,498	12	0,137	10	0,135	10
	2	0,0612	10	0,593	12	0,193	10	0,188	10
	4	0,0865	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
	Continuous	0,546	10	1,77	12	0,547	10	0,549	10
W_b	1	0,0314	10	0,342	12	0,0991	10	0,0968	10
	2	0,0435	10	0,403	12	0,137	10	0,132	10
	4	0,0614	10	0,482	12	0,194	10	0,182	10
	8	0,0867	10	0,575	12	0,274	10	0,243	10
	16	0,123	10	0,685	12	0,387	10	0,309	10
	Continuous	0,387	10	1,22	12	0,388	10	0,388	10
W_c	1	0,0222	10	0,244	12	0,0703	10	0,0684	10
	2	0,0292	10	0,275	12	0,0923	10	0,0885	10
	4	0,0397	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
	Continuous	0,24	10	0,788	12	0,243	10	0,242	10
W_d	1	0,00669	10	0,0779	12	0,0212	10	0,0197	10
	2	0,00906	10	0,0852	12	0,0286	10	0,0264	10
	4	0,0116	10	0,0923	12	0,0366	10	0,033	10
	8	0,0148	10	0,101	12	0,0469	10	0,04	10
	16	0,0197	10	0,115	12	0,0611	10	0,0481	10
	Continuous	0,059	10	0,197	12	0,0611	10	0,0594	10
W_e	1	0,00342	10	0,0409	12	0,0108	10	0,00992	10
	2	0,00478	10	0,0452	12	0,0151	10	0,0135	10
	4	0,00637	10	0,0493	12	0,0201	10	0,0176	10
	8	0,00816	10	0,0535	12	0,0255	10	0,0214	10
	16	0,0102	10	0,0592	12	0,0311	10	0,0244	10
	Continuous	0,0295	10	0,0987	12	0,0311	10	0,0297	10
W_j	1	0,0435	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
	Continuous	0,554	10	1,81	12	0,555	10	0,557	10
W_k	1	0,0299	10	0,323	12	0,0944	10	0,0922	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
	Continuous	0,362	10	1,15	12	0,364	10	0,363	10
W_m	1	0,0149	10	0,165	12	0,0472	10	0,0456	10
	2	0,0197	10	0,185	12	0,0623	10	0,0594	10
	4	0,0264	10	0,211	12	0,0836	10	0,0775	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
	Continuous	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 instruments

Weighting	Number of saw-tooth cycles per burst	r.m.s.	Tolerance %	MSDV	Tolerance %
Band limiting	1	0,0341	10	1,671	10
	2	0,0487	10	2,386	10
	4	0,069	10	3,38	10
	8	0,0982	10	4,811	10
	16	0,139	10	6,81	10
	Continuous	0,439	10	21,51	10
W_f	1	0,0197	10	0,9651	10
	2	0,0236	10	1,156	10
	4	0,0304	10	1,489	10
	8	0,0416	10	2,038	10
	16	0,0571	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 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 a further 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 an overload indication and the method for clearing a latched indication.

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 five 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 s	**Time to 10 % of original signal value** 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 s	**Time to 10 % of original signal value** s	**Equivalent decay rate** 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 be 1 s or better.

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.

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 International Standard. 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 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 measurement uncertainty.

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

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 may 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 a.c. 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 a.c. power-frequency fields and radio-frequency fields

Exposure of the complete instrument (or applicable components designated in the instrument documentation) to specified a.c. 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 a.c. power-frequency and radio-frequency fields.

Immunity to a.c. power-frequency fields applies to exposure to a uniform root-mean-square 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 a.c. 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 root-mean-square electric field strength of 10 V/m.

NOTE The instrument documentation may state that the vibration meter conforms to the specifications of this International Standard at an unmodulated root-mean-square electric field strength greater than 10 V/m.

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

For meters with an a.c input power port or an a.c. 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 may 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 a 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 International Standard 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 a vibration meter and the effects, if any, of such devices on the electrical characteristics of the instrument. Auxiliary devices include printers, computers and tape recorders.

9 Instrument marking

An instrument that conforms to all applicable specifications of this International Standard shall be marked, or shall display a reference to this International Standard 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 International Standard.

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 International Standard.

a) Pattern evaluation (targeted at manufacturers): A full set of tests, to be performed on samples of an instrument type. Pattern evaluation may be used for product type testing or pattern approval of vibration measuring instruments. The objective of these tests is to demonstrate an instrument design can meet the specifications defined in this International Standard.

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

   — periodically (e.g. prior to, or at the time of purchase, and every 1 or 2 years thereafter) to verify that the performance remains within the specifications of this International Standard,

   — to demonstrate that one-off instrument systems comply with the requirements of this International Standard, and

   — following modification or repair that may affect the performance of the instrument.

c) *In-situ* check (targeted at users): A minimum level of testing, indicating that an 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**	**Verification testing**	***In-situ* check**
5.1	General characteristics			12.5	13.5	14.2
5.2	Display of signal magnitude			12.5	13.5	
5.3	Electrical output	●		12.17		
5.4	Vibration sensitivity		●	12.7	13.7	14.3
5.5	Accuracy of indication at reference frequency under reference conditions	●		12.7	13.7	
5.6	Frequency weightings and frequency responses	●	●	12.11 Annex H	13.10 Annex H	
5.7	Amplitude linearity	●	●	12.10	13.9	
5.8	Instrument noise		●	12.12	13.11	
5.9	Signal-burst response	●		12.13	13.12	
5.10	Overload indication	●	●	12.10, 12.14	13.9, 13.12	
5.11	Under-range indication	●	●	12.10	13.9	
5.12	Time averaging	●		12.13	12.12	
5.13	Running r.m.s. acceleration	●		12.13	13.12	
5.14	Reset			12.15	13.14	
5.15	Timing facilities			12.18		
5.16	Electrical cross-talk	●		12.8	13.8	
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	13.5	
9	Instrument marking			12.4	13.4	
10	Instrument documentation			12.4	13.4	

12 Pattern evaluation

12.1 Introduction

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

Conformance to a specification of this International Standard 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, lies fully within the specified tolerance limits.

Uncertainties of measurement shall be determined in accordance with the GUM. The actual expanded uncertainties shall be calculated by the testing laboratory, with a coverage factor of no less than two.

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 International Standard. Testing laboratories shall not perform tests to demonstrate conformance to the specifications of this International Standard 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:

$$d = \frac{\sqrt{a_{\text{tot}}^2 - a_1^2}}{a_1} \times 100\ \% \qquad (14)$$

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.

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 International Standard.

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 vibration calibrator 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}, i.e.:

$$\varepsilon = \frac{a_{\text{test}} - a_{\text{ref}}}{a_{\text{ref}}} \times 100\ \% \tag{15}$$

The reference vibration transducer shall be used to measure the value of the mechanical vibration input generated at the reference vibration value and at the 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 of no less than 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 10 times the value of the background noise.

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 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 (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 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. 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 specified 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 for calibration in accordance with 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 the signal value that caused the first indication of overload down to 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 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 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 specified 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 and until the first indications of overload. 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 may 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	
	Electrical tests	Mechanical tests
Hand-arm	4 Hz to 2 000 Hz	8 Hz to 2 000 Hz
Whole-body	0,25 Hz to 160 Hz	0,5 Hz to 160 Hz
Low-frequency whole-body	0,05 Hz to 1 Hz	0,4 Hz and 0,5 Hz

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 Methods for testing the frequency response of the phase component of the frequency weightings are given in 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 accelerometers shall be mounted for calibration in accordance with ISO 16063-21.

At the reference frequency, the input mechanical vibration shall be adjusted to produce an unweighted vibration reading on the test instrument 20 dB above the lower limit of the specified linearity range. The unweighted 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 $\varepsilon(f)$ at frequency f, is given by

$$\varepsilon(f) = a_{\mathrm{ind}} - a_{\mathrm{in}}(f)\,w(f) \tag{16}$$

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:

$$\varepsilon(f) = \varepsilon_t(f) + \varepsilon_e(f) \tag{17}$$

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, i.e.:

$$\varepsilon_t = \sqrt{\varepsilon_m^2 + u_m^2} \tag{18}$$

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 to produce a band-limiting vibration reading on the test instrument 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 electric component of the frequency response error, $\varepsilon_e(f)$ at frequency f, is given by:

$$\varepsilon_e(f) = a_{ind} - \frac{u_{in}(f)}{S} w(f) \tag{19}$$

where $w(f)$ is the frequency weighting factor at frequency f, and S is the sensitivity, given by

$$S = \frac{u_{in}(f_{ref})}{a_{ind}} \tag{20}$$

At any frequency, the r.m.s. value of the input signal plus instrument noise shall be at least 10 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 non-linearity 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 Equation (16)]. For frequency weightings tested only using the electrical test, the overall frequency weighting error must 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.

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 $1/(5f_2)$, 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 may be produced when generating the saw-tooth wave. To avoid the test being affected by these, a single-pole low-pass filter may 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 Tables 7 to 9, as appropriate for the application. The signal-burst response errors shall be within the tolerance limits given in Tables 7 to 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 may 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 total vibration 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 5349-1, ISO 2631-1, ISO 2631-2 and ISO 2631-4). 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 that 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 A.c. electrical output

An electrical signal, corresponding to the reference vibration magnitude 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 a.c. 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 shall be 0,01 %.

12.19 Power supply

With the vibration field 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 meter 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 vibration field 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 vibration calibrator, relative to vibration value produced under reference environmental conditions, shall be accounted for in accordance with the procedure in the instrument documentation.

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

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

12.20.2 Expanded uncertainties for measurements of environmental test 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 vibration field 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 vibration field calibrator and the power to both instruments shall be switched off during an acclimatization period.

The vibration field 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 vibration field 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 vibration field 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

— 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 %, and

— 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 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 61000-4-2:2001, Clause 6. The test set-up and test procedure shall be in accordance with the specifications given in IEC 61000-4-2:2001, 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 10 times by contact and 10 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 22:2003, 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 centres.

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 22:2003, 8.1, 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 22:2003, 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 a.c. 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 a.c. power-frequency fields and radio-frequency fields.

The immunity of any vibration meter to a.c. 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 a.c. 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 a.c. 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 a.c. 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 a.c. power-frequency or radio-frequency field is applied, the change in the indicated vibration value shall not exceed ± 10 %.

For meters with an a.c. input power port and, if available, an a.c. 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 root-mean-square 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 61000-6-2:1999, Table 4. Additional specifications for immunity to voltage dips, voltage interruptions and voltage surges shall be as described in IEC 61000-6-2:1999, 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 61000-6-2:1999, Table 2, apply for immunity to radio-frequency common mode interference over the frequency range from 0,15 MHz to 80 MHz for a root-mean-square 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 61000-6-2:1999, 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 a.c. 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 International Standard.

The additional test information noted in IEC 61000-4-3:2002, 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, a.c. power-frequency field tests or radio-frequency field tests shall be reported.

13 Verification tests

13.1 Introduction

This clause provides details of the tests necessary for verification of conformance of a vibration instrument to the specifications of this International Standard, together with the test methods to be used.

Verification to a specification of this International Standard 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, lies fully within the specified tolerance limits.

Uncertainties of measurement shall be determined in accordance with the GUM. The actual expanded uncertainties shall be calculated by the testing laboratory, with a coverage factor of no less than two.

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 International Standard. Testing laboratories shall not perform tests to demonstrate verification to the specifications of this International Standard 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, or the test is irrelevant.

Where one-off systems have a restricted range of environmental application, this shall be stated.

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

13.2 Testing requirements

Those instruments used for verification 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 environmental conditions prevailing at the time of a test shall be within the following ranges:

— air temperature: 19 to 27°C;

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

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

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

13.3 Submission for a test

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.

13.4 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.

13.5 Mandatory facilities and general requirements

It shall be confirmed that the vibration meter conforms 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.

It shall be confirmed that the display conforms to the specifications of 5.2.

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

It shall be confirmed that the vibration meter has a band-limiting weighting filter, at least for verification testing.

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 International Standard.

13.6 Initial instrument preparation

Before conducting any tests, the instrument shall be provided with a power supply within the operating limits specified by the manufacturer. The instrument, transducer and vibration calibrator 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.

13.7 Indication at the reference frequency under reference conditions

Any error in the indication of the reference acceleration value at the reference frequency 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}; see Equation (15).

The reference vibration transducer shall be used to measure the value of the mechanical vibration input generated at the reference vibration value and at the reference frequency, before measuring the vibration magnitude with the vibration meter. For these measurements the vibration meter shall be set to the band-limiting frequency weighting and linear time averaging, with a measurement duration of not less than

30 s for hand-arm vibration, 1 min for whole-body vibration, and 5 min for low-frequency whole-body applications. The value of the input signal plus background noise shall be at least 10 times the value of the background noise.

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) to 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 to within the tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

13.8 Electrical cross-talk

For instruments with more than one measurement channel (e.g. triaxial measurement instruments), tests shall be carried out on 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 amplitude of the test signal shall be within the upper 5 dB of the reference 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.

13.9 Amplitude linearity and under-range indication

The amplitude linearity of an instrument shall be tested with steady sinusoidal electrical signals at the reference frequency. Amplitude linearity shall be tested with the instrument set to time-averaged measurement with a band-limiting frequency weighting.

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

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 and at the reference frequency, the value of the 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 causes the first indication of overload. The signal value shall then be decreased in the 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 reference frequency input signal value, from the specified lower boundary of the reference measurement range to the first indication of overload, amplitude-linearity errors shall be within the applicable tolerance limits given in 5.7. The extent of the reference frequency linear operating range over the reference measurement range shall comply with the linear operating range requirements given in 5.7 between the nominal vibration magnitudes specified for the upper and lower boundaries. The electrical frequency weighting is unity at the reference frequency for an indication of the reference vibration magnitude on the reference measurement range. The maximum expanded uncertainties of measurement are 2 %.

Following tests on the reference measurement range, the amplitude linearity shall be tested additionally on the highest and lowest measurement ranges. Tests shall be carried out at the reference frequency and at the 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 tested, 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 up to 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 should be not less than 30 s for hand-arm vibration, or 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.

13.10 Frequency weightings and frequency responses

13.10.1 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 is 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.

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 may 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 one octave across the frequency ranges specified in Table 15.

NOTE Methods for testing the frequency response of the phase component of the frequency weightings are given in Annex H.

13.10.2 Mechanical tests of frequency response

The mechanical frequency response of the vibration instrument shall be determined by comparison with un-weighted acceleration measurements made by an appropriately calibrated laboratory reference vibration transducer. The error in frequency response shall be the indication of the 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 accelerometers shall be mounted for calibration in accordance with ISO 16063-21.

At the reference frequency, the input mechanical vibration shall be adjusted to produce an un-weighted vibration reading on the test instrument 20 dB above the lower limit of the specified linearity range. The un-weighted 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 mechanical vibration 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 $\varepsilon(f)$ at frequency f is given by Equation (16).

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. Signal values displayed by the instrument shall also be corrected, as required, for any non-linearity between the indication at the test frequency and the indication at the reference frequency.

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

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

13.10.3 Electrical tests of frequency response

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

At the reference frequency, the input electrical signal shall be adjusted to produce a band-limited vibration reading on the test instrument 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 electric component of the frequency response error $\varepsilon_e(f)$ at frequency f is given by Equation (19).

At any frequency, the r.m.s. value of the input signal plus instrument noise shall be at least 10 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 non-linearity 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.

13.10.4 Verification

For those frequency weightings tested using the mechanical tests, the frequency-weighting error is provided directly from the test [i.e. $\varepsilon(f)$ in Equation (16)]. For frequency weightings tested only using the electrical test, then the overall frequency-weighting error must 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.

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 be verified as conforming to the design goals and tolerance limits stated in the instrument documentation.

13.11 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 time-averaged 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.

13.12 Signal-burst response

With the instrument set to the reference measurement range and the applicable band-limiting weighting, a continuous saw-tooth 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 eight-cycle signal bursts specified in Table 6 shall then be applied to all available frequency and time weightings.

The fall time of the saw-tooth wave shall be not more than $1/(5f_2)$, 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 prevent these affecting this test, a single-pole low-pass filter may 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. $100f_2$).

Measurements of signal-burst response shall be repeated with the value of the steady input signal reduced by factors of 100 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.

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

13.13 Overload indication

Overload indications shall be tested by applying positive and negative one-half-cycle, sinusoidal electrical signals at the reference frequency, with the instrument set to band-limiting frequency weighting, the reference measurement range 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 may 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.

13.14 Reset

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

13.15 Combined axis outputs

This test ensures that multi-axis values are combined in accordance with the appropriate measurement standard when the combined axis output is displayed (e.g. total vibration value).

The vibration 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 5349-1, ISO 2631-1, ISO 2631-2 and ISO 2631-4). 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.

13.16 Test report

Full details shall be given in the test report of the test configurations, test conditions and test results, including the corresponding actual expanded uncertainties of measurement. The test report shall state that the complete instrument has been verified, or has not been verified, as conforming to the specifications of this International Standard.

14 *In-situ* checks

14.1 Introduction

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.

14.2 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 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.

14.3 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 instrument, to be carried out at the reference vibration value on the reference measurement range and at the calibration check frequency using the specified vibration calibrator;
- 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 may 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 calibrator, the initial sensitivity and adjustments made to the sensitivity.

Annex A
(normative)

Specification for vibration field calibrator

A.1 General

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

A.2 Specification

A mechanical field 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 International Standard 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
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. (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
Degree of protection against dust and splash water:	dependent on application, must 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 calibrator (e.g. in the form of a calibration certificate or in the instrumentation documentation) shall list the expected readings as weighted accelerations (all possible modes of a vibration meter) for all combinations of selectable frequencies and magnitudes of the calibrator.

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

Characteristic	Measurement type			
	Hand-arm		Whole-body	Low-frequency whole-body
Frequency	500 rad/s ± 0,5 % (79,577 Hz)	1 000 rad/s ± 0,5 % (159,155 Hz)	100 rad/s ± 0,5 % (15,915 Hz)	2,5 rad/s ± 0,5 %[a] (0,3979 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 calibrators are not currently available at such low frequencies, and that vibration pick-up 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 $2g$ 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 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 calibrator. The procedure is to measure the r.m.s. acceleration and frequency produced by the calibrator. The field 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.

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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 were calculated from the design goals defined by Tables 3 and 4 and 5, and Equations (8) to (12).

The frequency-weighting values given in the Tables are based on true one-third-octave centre frequencies, f_{c}, given by:

$$f_{\text{c}}(n) = 10^{n/10} \text{ Hz} \tag{B.1}$$

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

The centre frequencies are as defined in IEC 61260 using $\log_{10}$ 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.

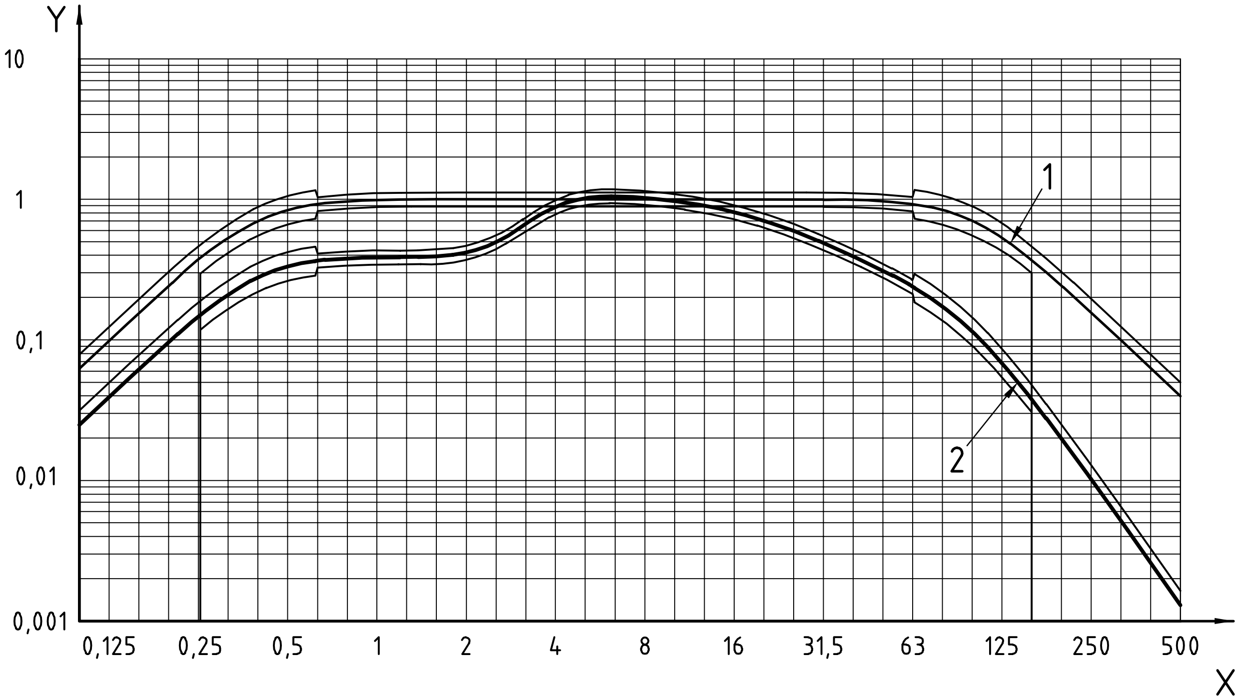
NOTE 1 Some measurement standards have tabulated frequency weightings based on the nominal centre frequencies. In this International Standard the frequency weightings are based on the actual centre frequencies; this can result in some weighting factors being different from those in the measurement standards.

The weighting filters tabulated in this Annex are the overall frequency weightings [defined by Equation (12)], 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.

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		Band-limiting			Weighting W_b			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	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	0,0244	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

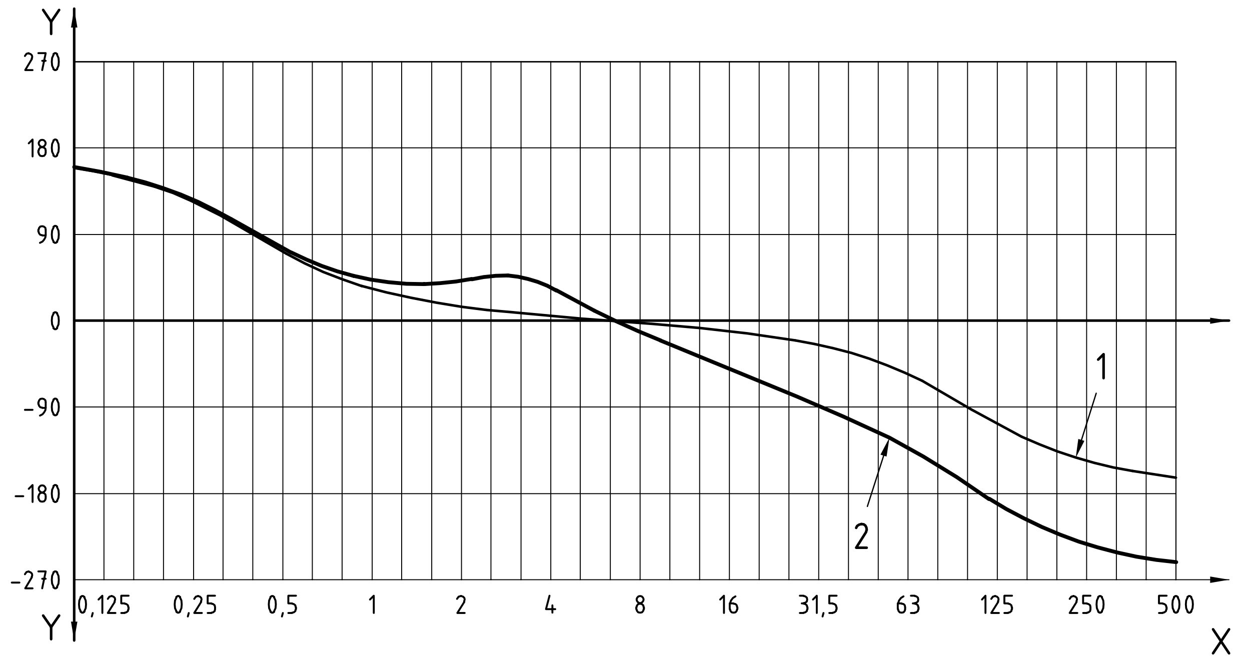
X frequency, Hz

Y weighting factor

1 band-limiting

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

Y phase (degrees)

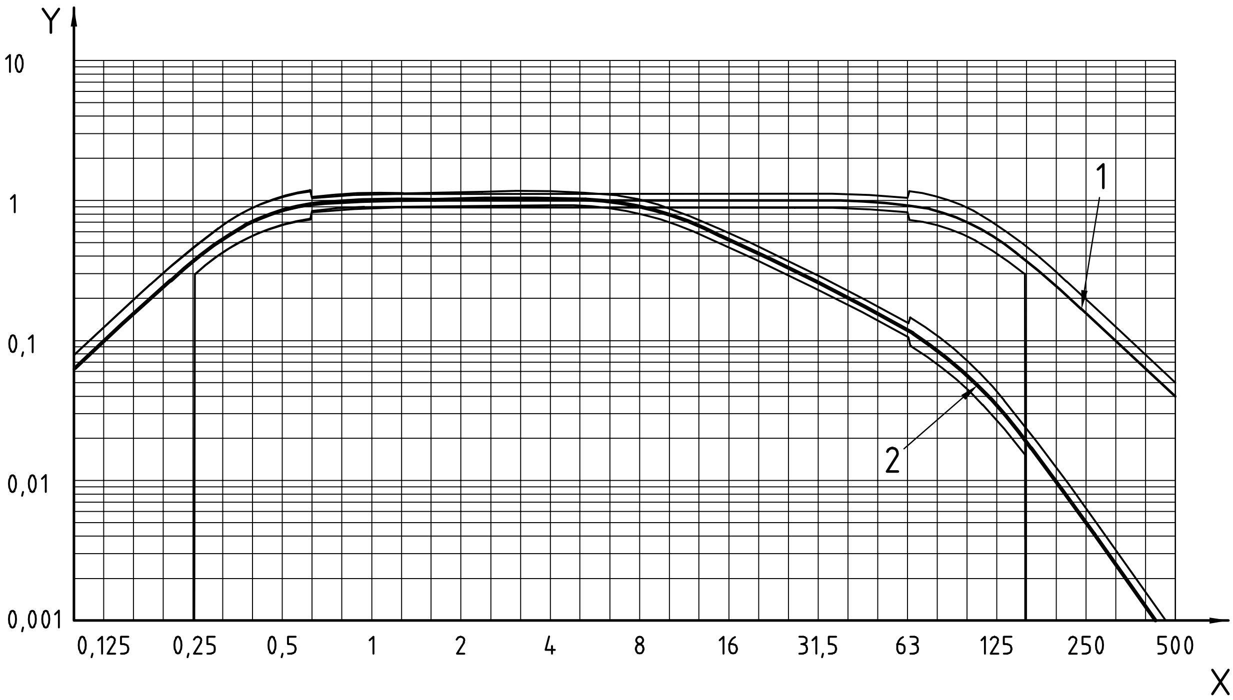
1 band-limiting

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		Band-limiting			Weighting W_c			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	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	0,0244	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

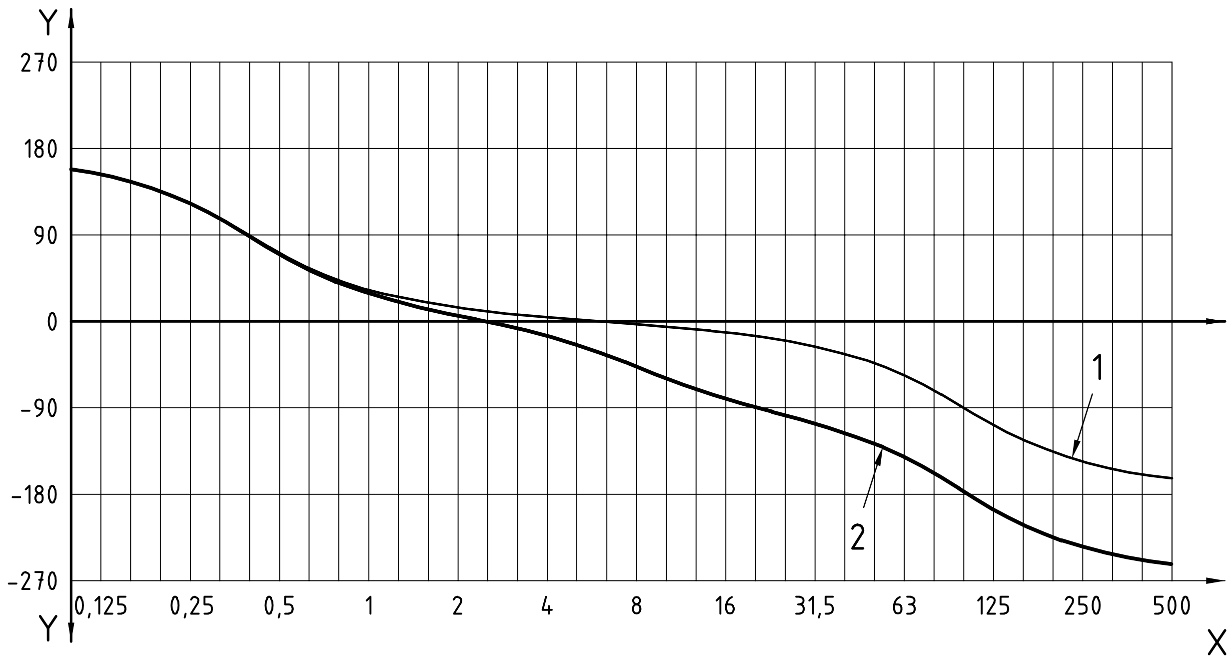
X frequency, Hz

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)

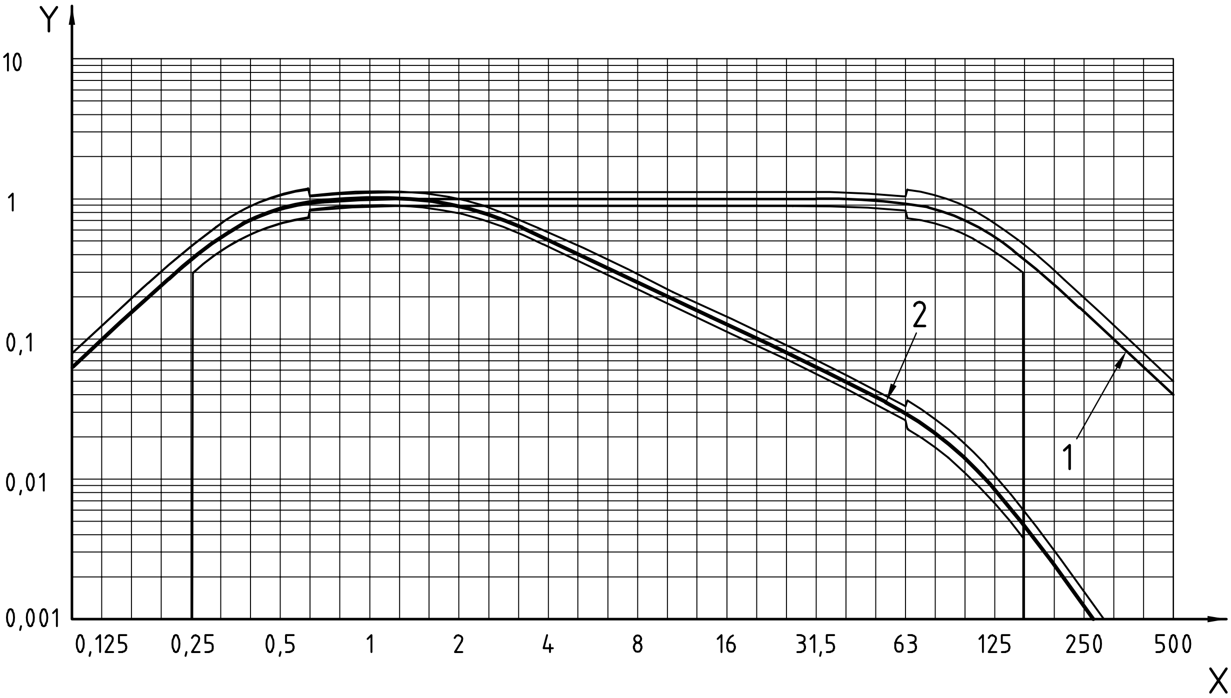
1 band-limiting

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		Band-limiting			Weighting, W_d			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	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	0,0244	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

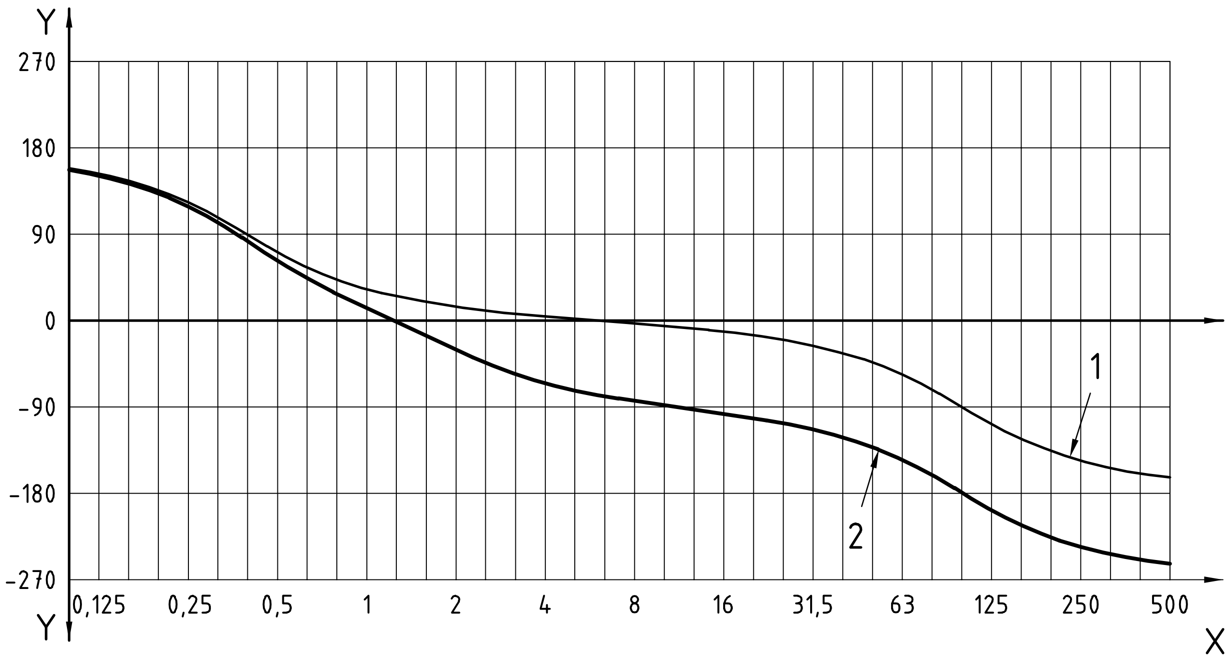
X frequency, Hz

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)

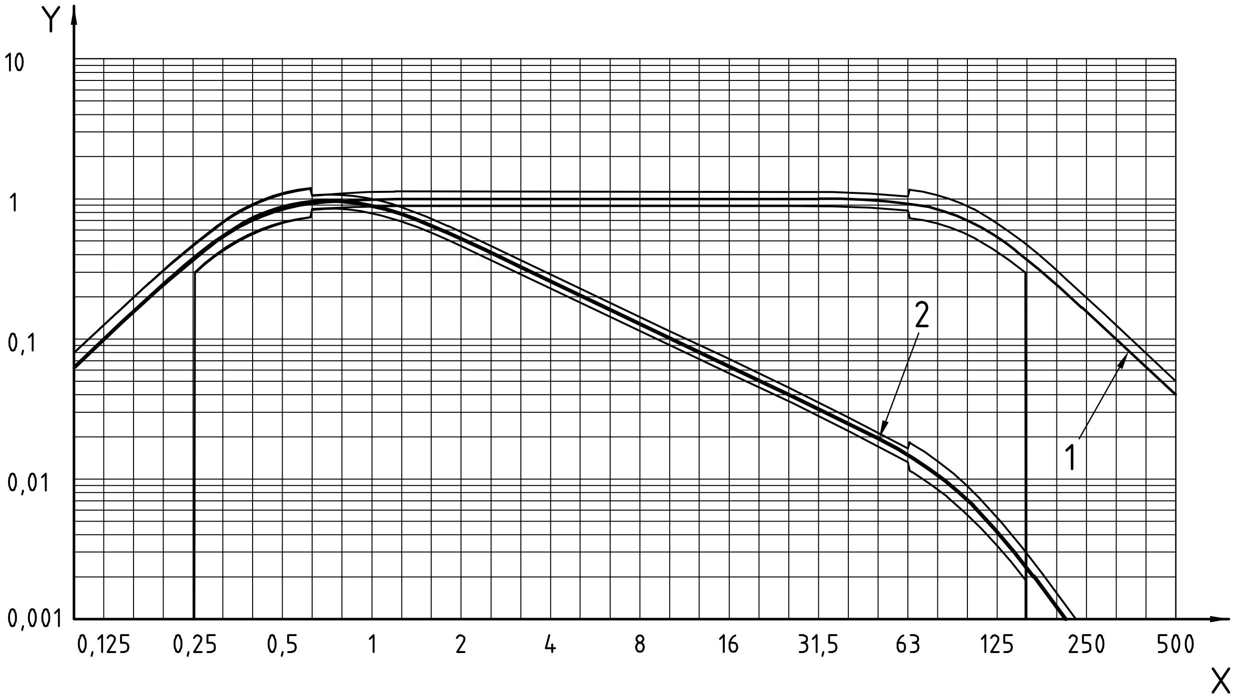
1 band-limiting

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		Band-limiting			Weighting, W_e			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	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	0,0244	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

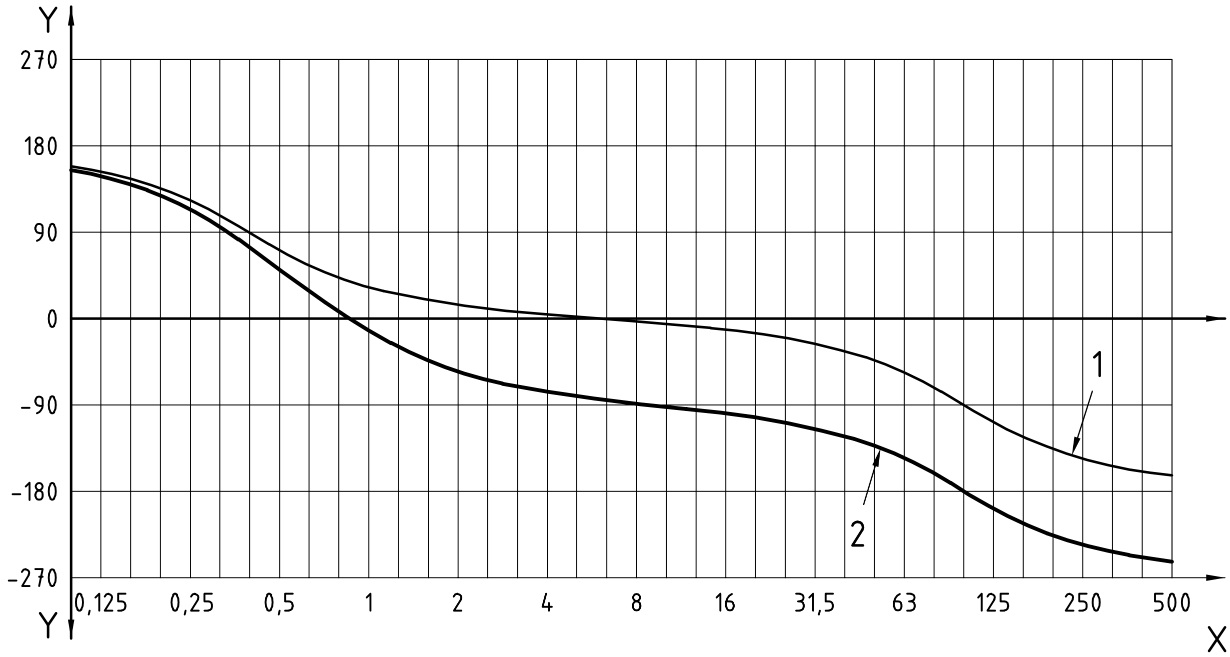
X frequency, Hz

Y weighting factor

1 band-limiting

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

Y phase (degrees)

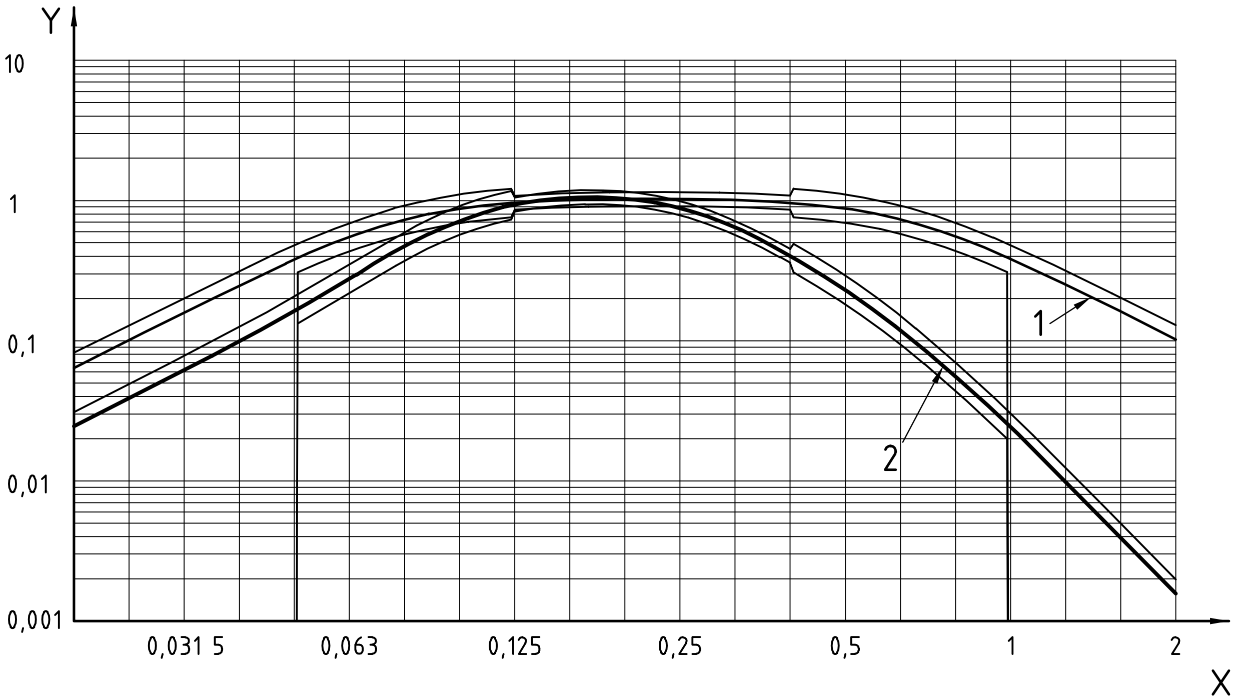
1 band-limiting

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		Band-limiting			Weighting, W_f			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	dB	$\Delta\varphi_0$ degrees
−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 5	−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

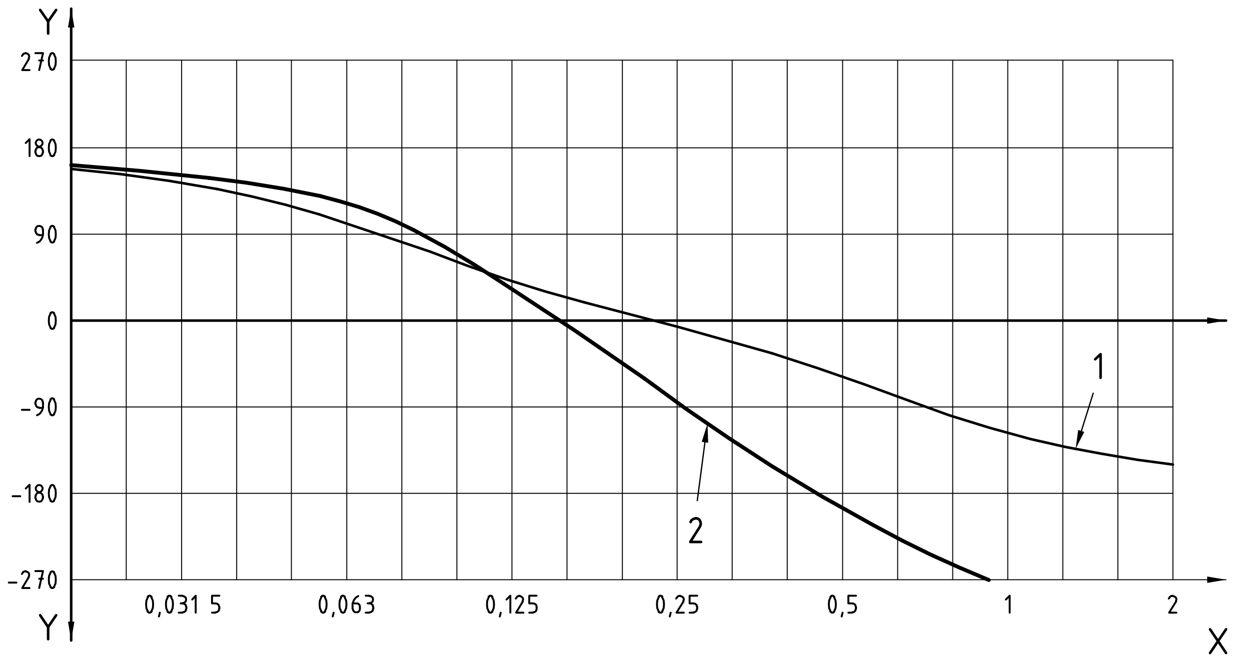
X frequency, Hz

Y weighting factor

1 band-limiting

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

Y phase (degrees)

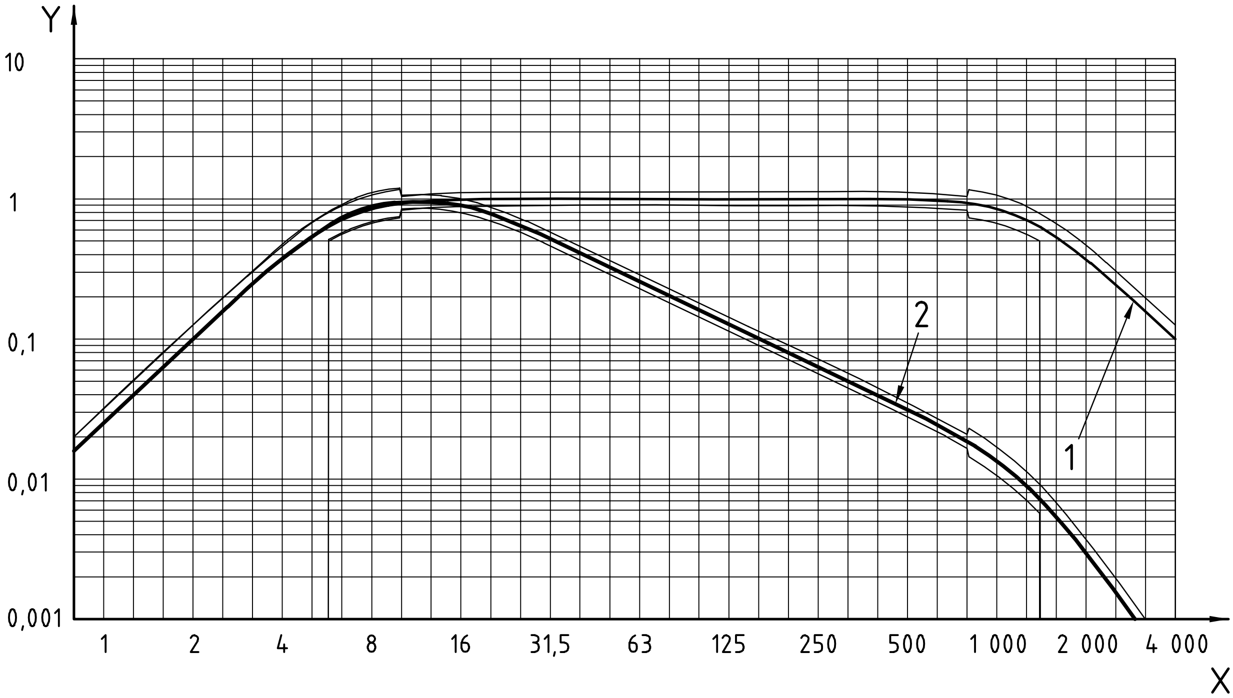
1 band-limiting

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		Band-limiting			Weighting, W_h			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	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	0,6471	−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

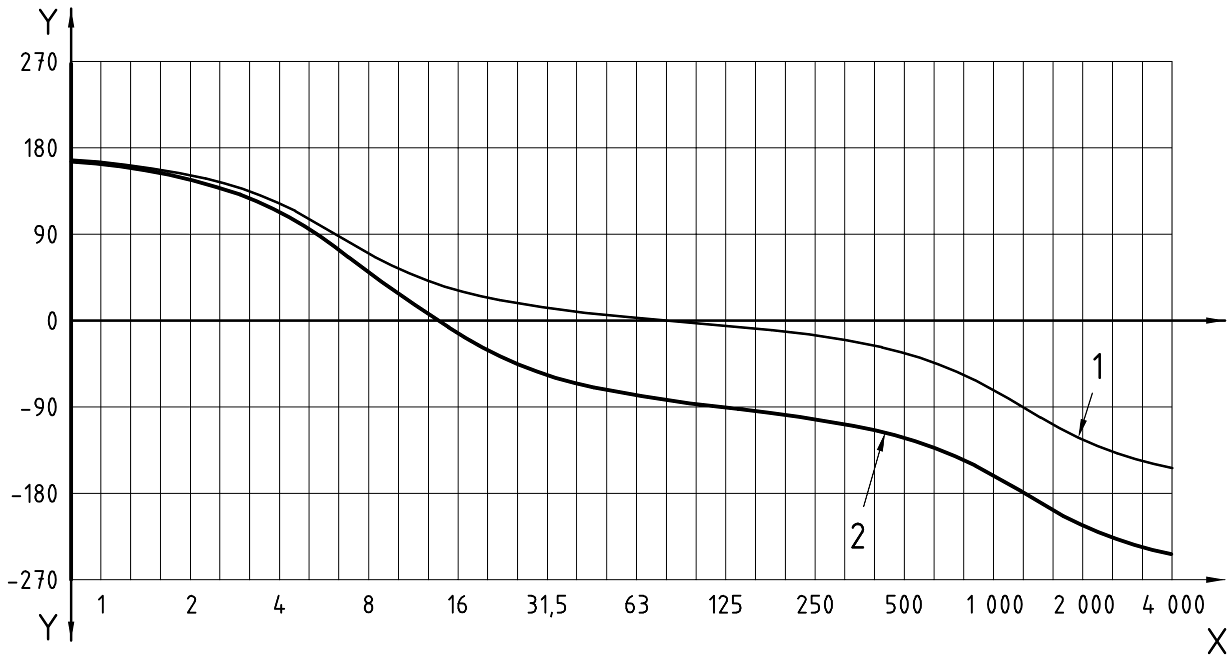
X frequency, Hz

Y weighting factor

1 band-limiting

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

Y phase (degrees)

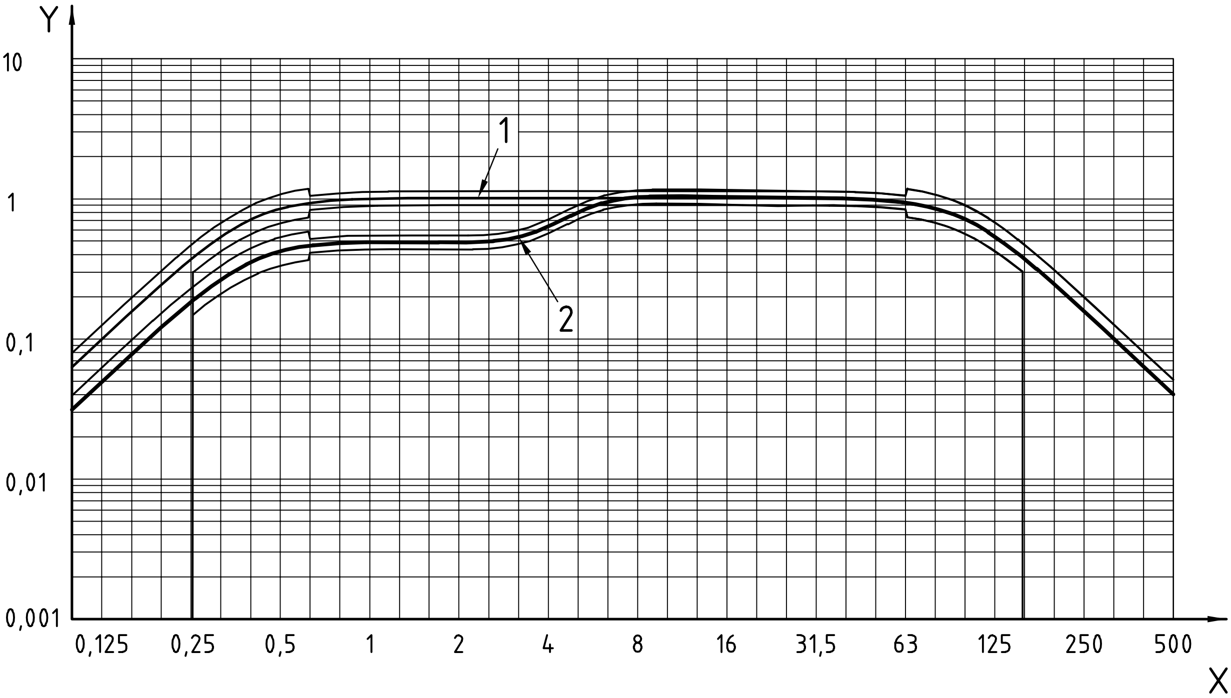
1 band-limiting

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		Band-limiting			Weighting, W_j			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	dB	$\Delta\varphi_0$ 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	0,0244	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

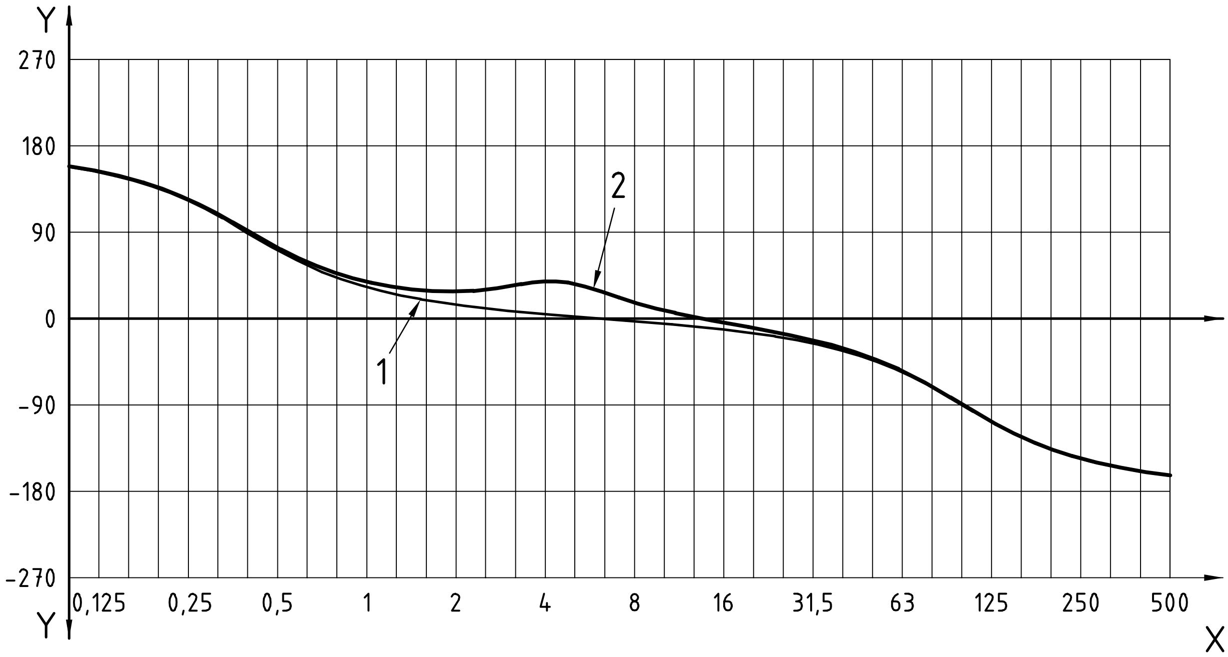
X frequency, Hz

Y weighting factor

1 band-limiting

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

Y phase (degrees)

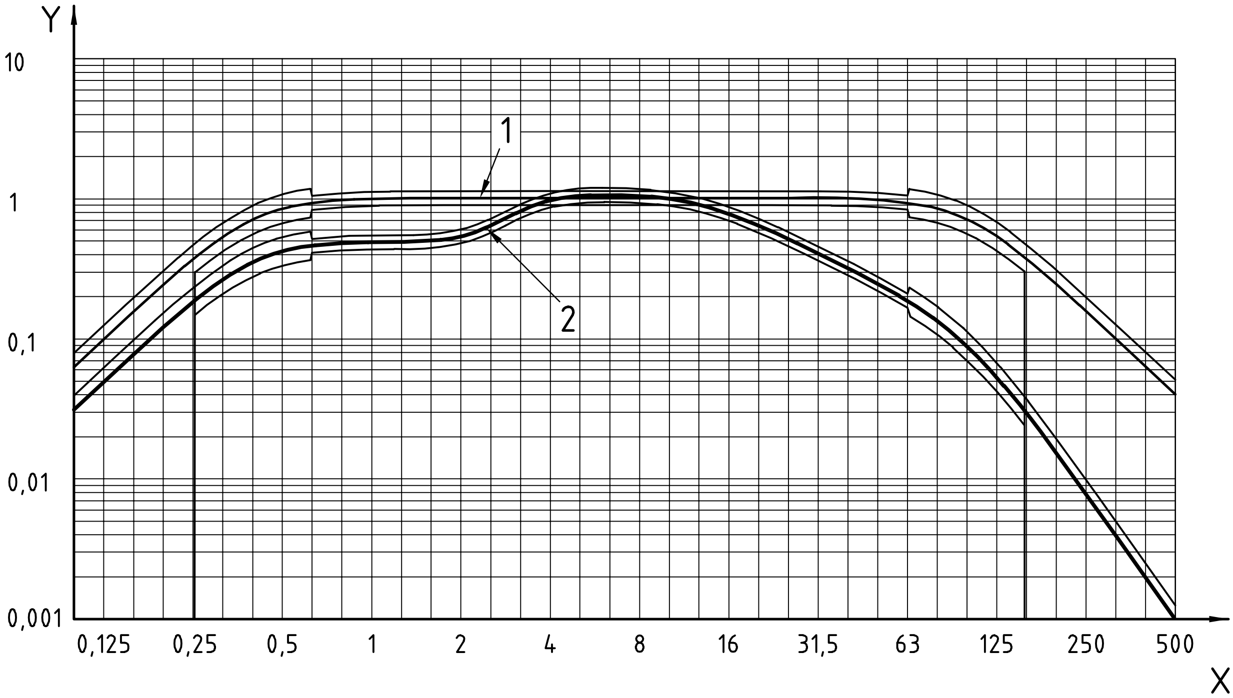
1 band-limiting

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		Band-limiting			Weighting, W_k			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	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	0,0244	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

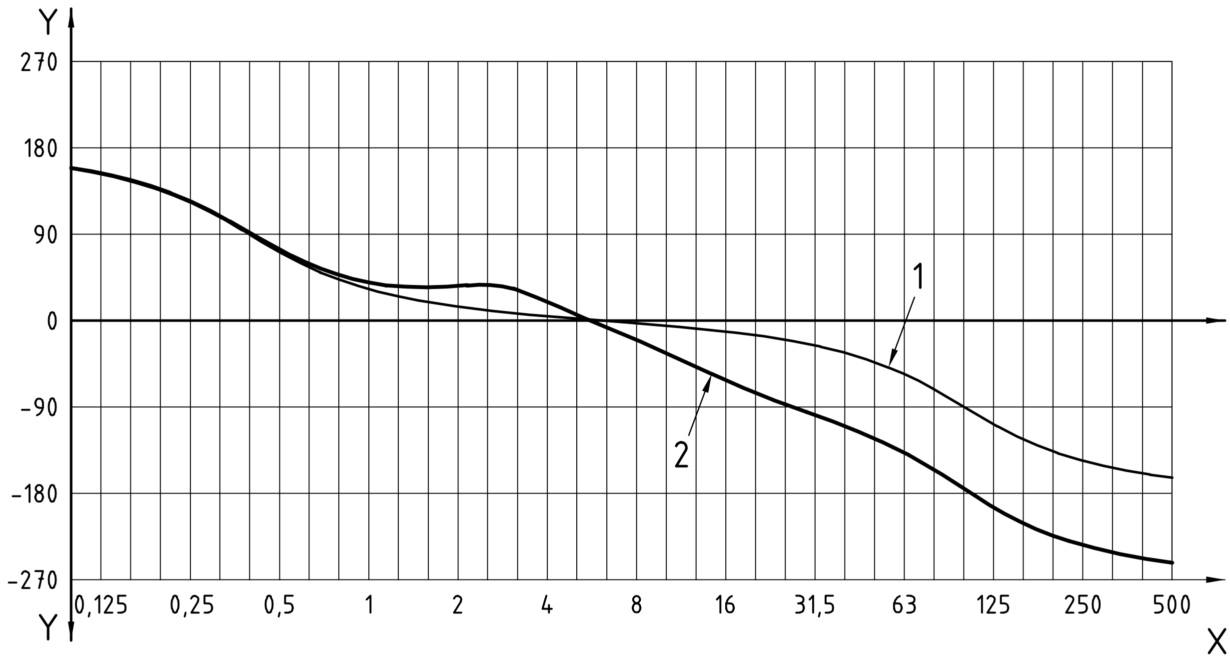
X frequency, Hz

Y weighting factor

1 band-limiting

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

Y phase (degrees)

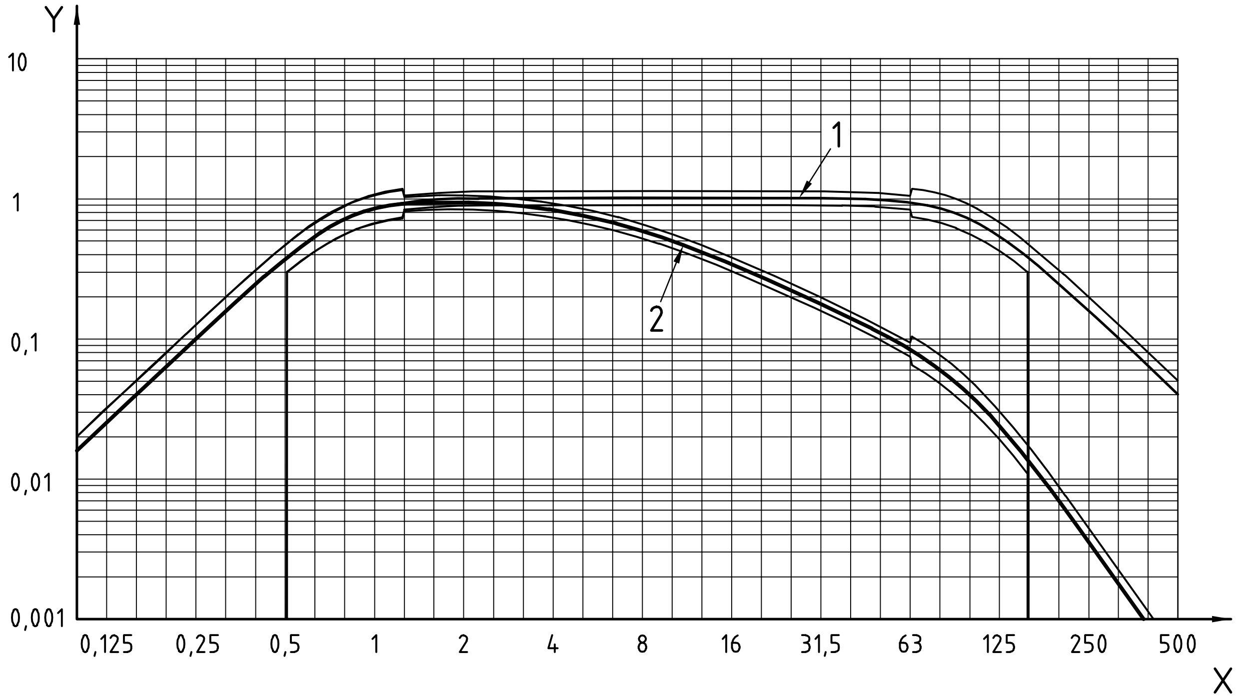
1 band-limiting

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		Band-limiting			Weighting, W_m			Tolerance		
	Nominal	True	Factor	dB	Phase degrees	Factor	dB	Phase degrees	%	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

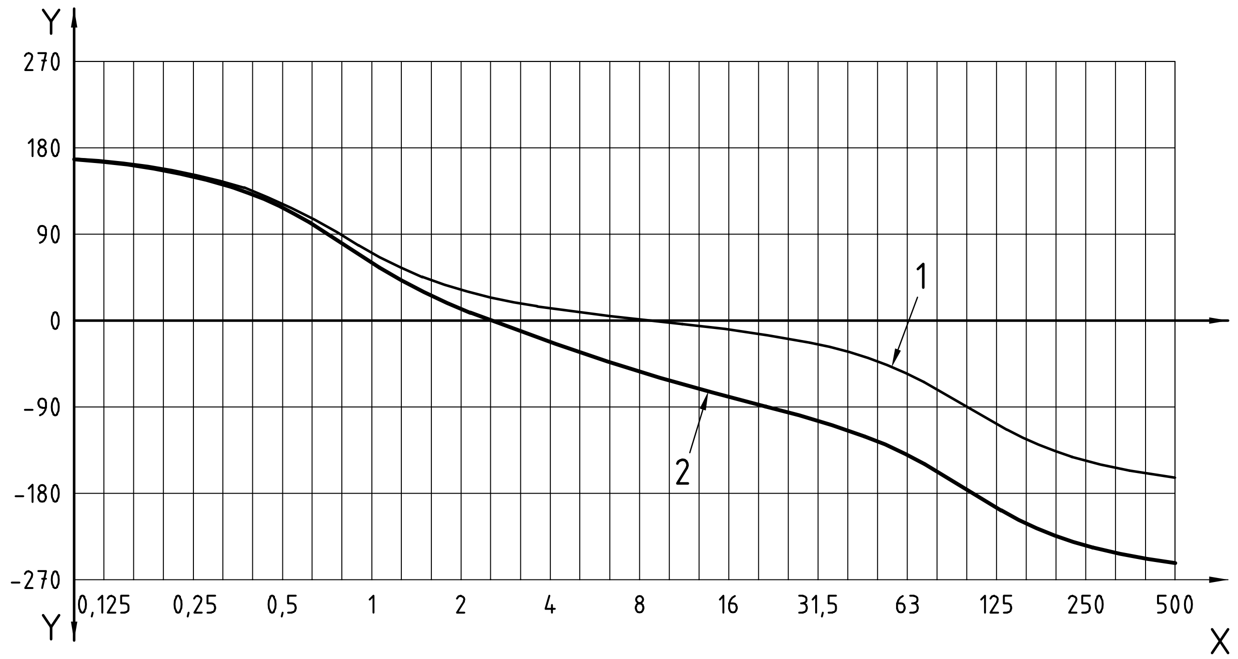
X frequency, Hz

Y weighting factor

1 band-limiting

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

Y phase (degrees)

1 band-limiting

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, analog or digital, real-time, one-third-octave or FFT analysis, may be used to produce the frequency-weighted r.m.s. acceleration value by summation of the squares of the weighted r.m.s. spectral components a_i:

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

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 International Standard 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 Equation (C.1).

C.1.3 Fast Fourier Transform (FFT)

The weighted r.m.s. acceleration value can be obtained from the FFT r.m.s. spectral components using Equation (C.1) or the power spectral density components (P_i) using Equation (C.2). However, the weighting factors, w, should be obtained using Equations (8) to (12) 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 Equation (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 signal (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 five times the highest frequency in the nominal frequency range.

C.2 Time domain

C.2.1 Introduction

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 Equations (3) and (4)], the maximum value of a running r.m.s. signal is required (see Annex D). In this case, the frequency weighting should 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 analog 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 analog 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:

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

$H(z)$ can be expressed as:

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

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:

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

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 [8]). 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:

$$s = \frac{z-1}{T_\mathrm{s}\left(z+1\right)} \tag{C.6}$$

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 IIR filtering technique (Infinite Impulse Response) following Equation (C.5).

As an example, a MATLAB® 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'.[1)]

NOTE The MATLAB® 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 International Standard. The MATLAB code could be modified to allow lower sample rates, e.g. by use of the cotan transformation:

$$s = \frac{2\pi f_\mathrm{c}}{\tan\left(\pi f_\mathrm{c} T_\mathrm{s}\right)} \cdot \frac{z-1}{z+1}$$

where f_c 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 International Standard 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 filter to input signal vector x (output to signal vector 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
```

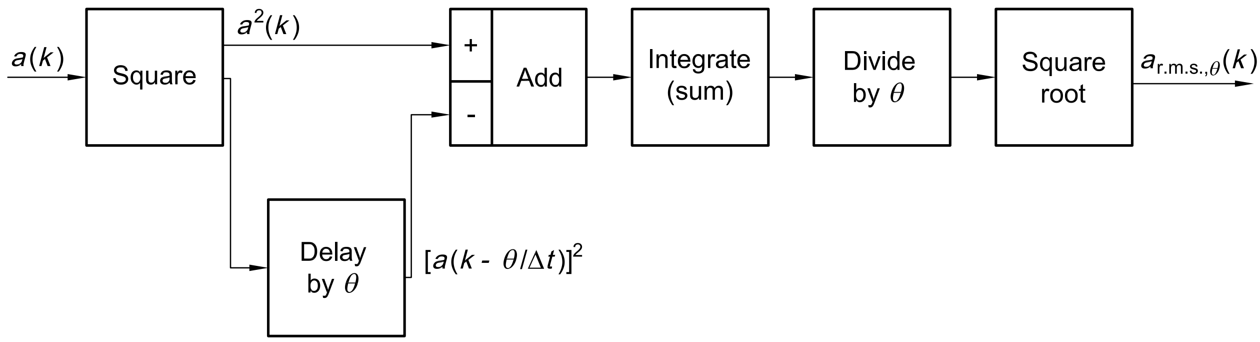
Figure C.1 — Example code for applying the frequency weighting W_k to a time signal

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, Equation (3), became 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 is the sample number

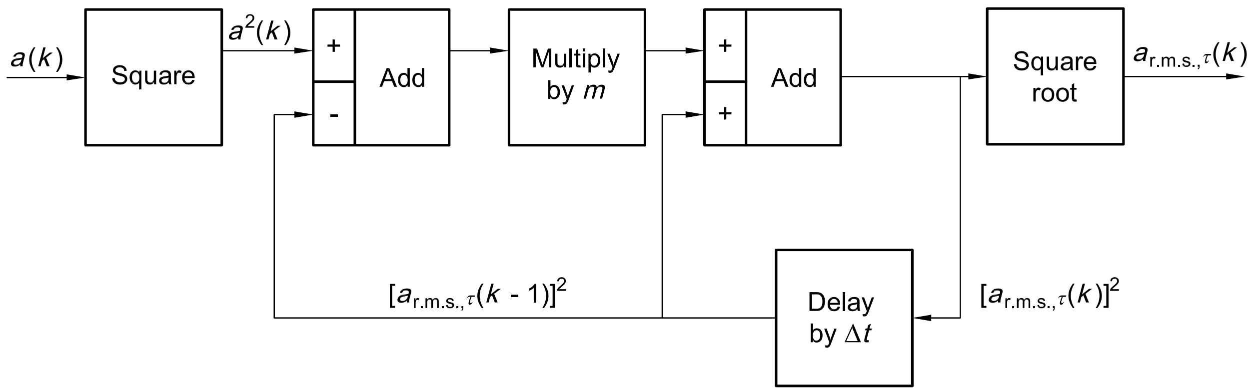
Δt is the sample period

θ is the 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, Equation (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 (ISO 8041:1990). 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

$m = 1 - \exp(-\Delta t/\tau)$

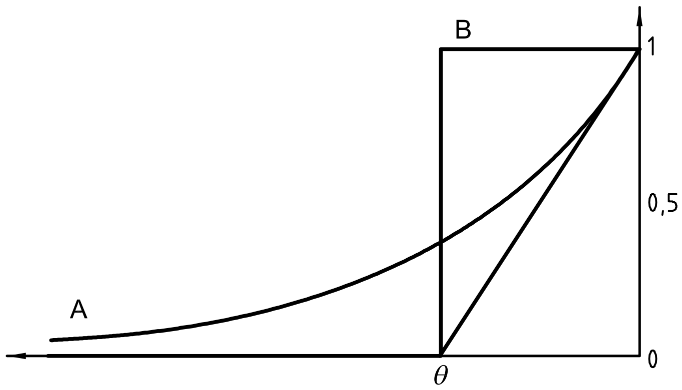
τ is the time constant

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 Equations (3) and (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 may occur depending on the length and the waveform of the shock.



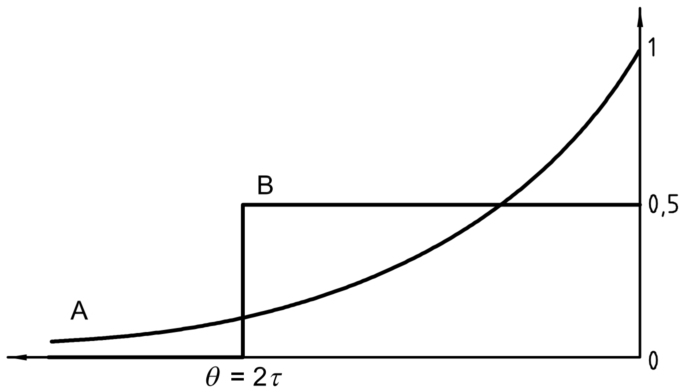
Key

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 confidence level (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 may 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 will depend 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 may require less demanding specifications; some may require more strict specifications.

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

E.2 Specifications

Recommended minimum specifications for vibration transducers are given in Table E.1 (these specifications may not be applicable in all cases).

Table E.1 — Vibration transducer specifications

Characteristic	Measurement issue — Influence on measurement uncertainty	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	On seat: 300 mm diameter × 12 mm height (semi-rigid disc, see F.2) Other locations: 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 ºC to 50 ºC	−10 ºC to 50 ºC	−10 ºC to 50 ºC	−10 ºC to 50 ºC
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 transducers to vibration along axes at 90° to the principal axis. See Notes 1 and 2.	< 5 %	< 5 %	< 5 %	< 5 %
Maximum unweighted shock acceleration	The vibration transducer needs to be capable of withstanding the high unweighted shock accelerations to which it may be exposed, while providing accurate information within the measurement frequency range.	30 000 m/s^2 (may 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 resonant frequency	Should be greater than approximately 10 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 may be required for certain applications (e.g. laboratory-based measurements may not need any IP specification while measurements in explosive atmospheres will need higher IP ratings).	IP 55	IP 55	None	IP 55

NOTE 1 The transverse sensitivity will be 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.

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 International Standard. The test mounting system and test accelerometer shall be those specified for use with the instrumentation being evaluated against this International Standard.

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.

NOTE 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 as shown in Figure F.1. The frequency range of the spectrum shall be at not less than 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 shall be within ± 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 and covering the frequency range not less than 31,5 Hz to 1250 Hz, of the outputs from the reference and mounted test accelerometers (see Annex C for additional information on narrow-band measurement parameters).

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.

If possible, initial tests should be carried out with the test accelerometer mounted directly on the test handle (i.e. rigidly mounted, using stud or glue, without the test mounting system). These additional tests will provide baseline data that can be used to normalize the final test results.

F.1.3 Test report

The instrument documentation shall include the following information:

a) reference transducer type and serial number;

b) frequency increment of the frequency analysis;

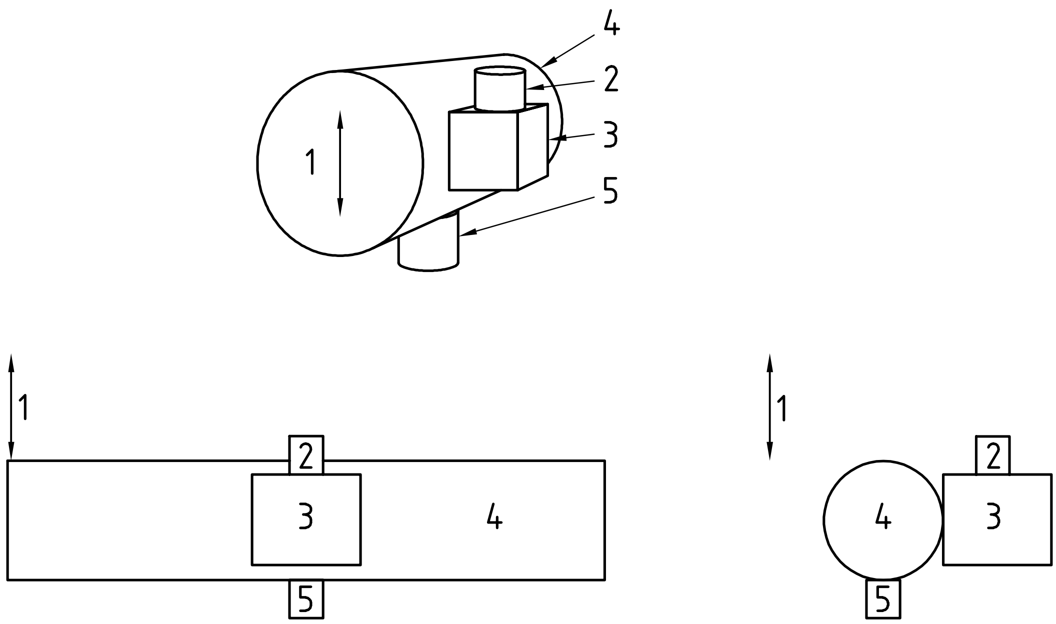
c) magnitude and frequency of the maximum deviation from the reference spectrum (as a percentage of the reference value) for each of the x-, y- and z-axis tests.

Optionally, a printout of the frequency response function from the tests may be provided

F.2 Whole-body measurement

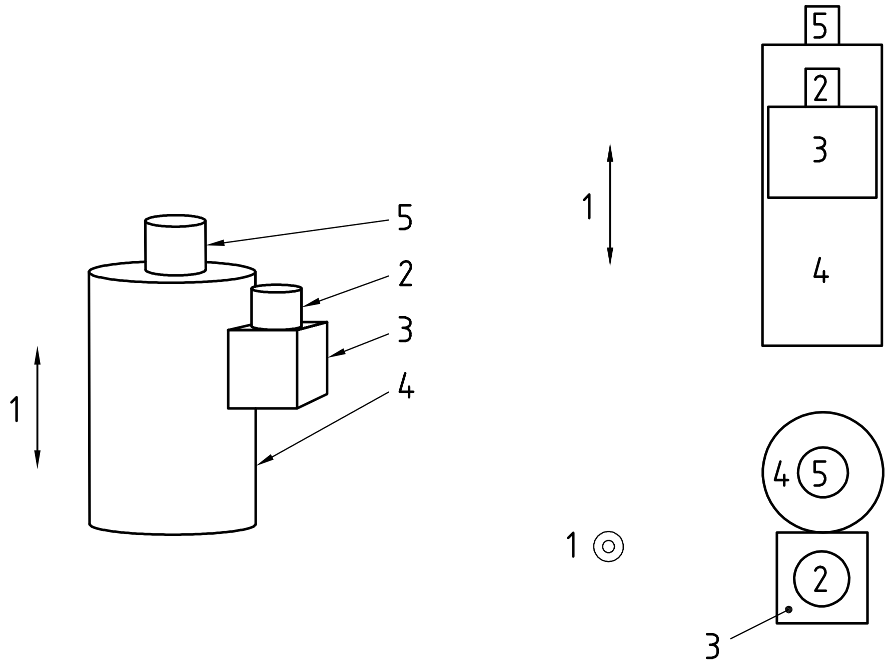
One mounting method for the measurement of whole-body vibration on the seat pan or backrest of a seated person is defined in ISO 10326-1.

ISO 10326-1 specifies, for laboratory tests of vehicle seat vibration, that the accelerometers shall be attached in the centre of a mounting disc with a total diameter of (250 ± 50) mm. The disc shall be as thin as possible. The height shall not be more than 12 mm. This semi-rigid mounting disc of approximately 80 Shore A to 90 Shore A moulded rubber or plastics material shall have a centre cavity in which to place the accelerometers. The accelerometers shall be attached to a thin metal disc with a thickness of (1,5 ± 0,2) mm and a diameter of (75 ± 5) mm.

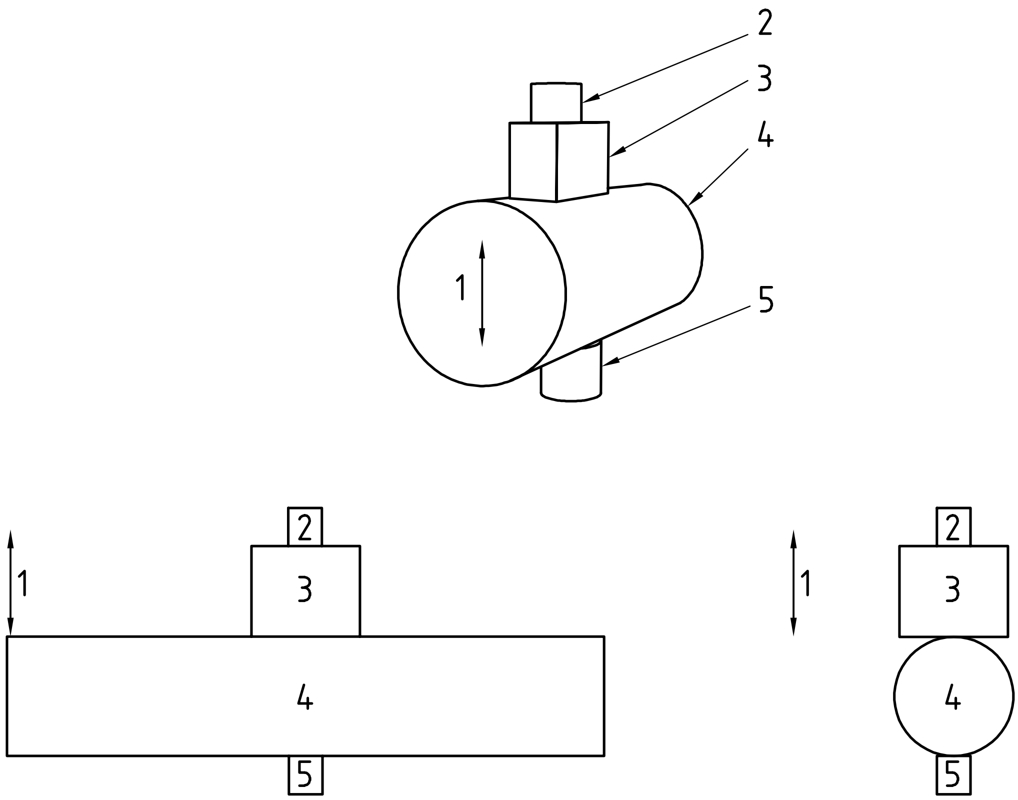


a) x-axis

Figure F.1 — Test configurations



b) *y*-**axis**



Key

1 input vibration axis

2 test transducer

3 test mounting system

4 handle

5 reference transducer

c) *z*-**axis**

Figure F.1 (*continued*)

Annex G
(normative)

Instrument documentation

G.1 General information

The following information shall be given:

a) reference to this International Standard;

b) date of pattern evaluation and the traceability of those tests to international metrology standards;

c) description of the complete instrument in the configuration for its normal mode of operation including, if applicable, extension cables, mounting system, mechanical filter or associated devices;

d) description of the accelerometer(s) recommended for use with the instrument;

e) description of the characteristics and operation of each independent channel of a multi-channel instrument;

f) identification of any accessories that may be needed for the instrument to conform to the specifications (e.g. mechanical filters, mounting systems or cables; dedicated software may also be an integral part of the instrument);

g) identification of alternative accessories required for specific applications, and the circumstances in which they shall be used (e.g. mounting devices or vibration transducers for high shock environments).

G.2 Design features

The following information shall be given:

a) descriptions of the quantities that the instrument is capable of measuring (e.g. time-weighted vibration value, time-averaged vibration value, and the vibration dose value), separately or in combinations;

b) description of the frequency weightings that conform to the specifications of this International Standard, and the band-limiting weighting;

c) description of the method, or methods, used for combining the single-axis data, including identification of frequency weightings and multiplying factors used, where combined axis data are presented;

d) information about the design-goal characteristics and the tolerance limits that shall be maintained for quantities that the instrument is capable of measuring but for which no performance specifications are provided in this International Standard; the characteristics include frequency weightings and frequency responses;

e) description of the time weightings;

f) description of the measurement ranges and the operation of the measurement range control;

g) description of all display devices, including the modes of operation of the digital display devices, and identification of the measurement quantities as displayed on each display device; if more than one display device is provided, a statement mentioning which of these devices conform to the specifications of this International Standard and which are for other purposes (see Note);

h) description of the normal mode of operation of the complete instrument;

i) identification of the optional facilities that are provided and for which performance specifications are given in this International Standard;

j) statement of the nominal vibration values at the upper and lower boundaries of the linear operating range at the reference frequency in each measurement range;

k) for each frequency weighting and frequency response provided, a statement of the lower and upper boundaries for the total range of nominal vibration values that can be measured, as a function of frequency and within the applicable tolerance limits;

l) description of the operation of any hold feature and the means for clearing a display that is held;

m) description of the operation of the reset facility for measurements of time-averaged vibration values, maximum vibration values, vibration dose values and maximum transient vibration values; statement of whether operation of the reset facility clears an overload indication; statement of the nominal delay time between the operation of the reset facility and the initiation of a measurement;

n) description of the operation and interpretation of overload and under-range indications and the means for clearing overload and under-range indications;

o) unique identification of any computer program software that is needed to operate the instrument and the procedure for its installation and use;

p) identification of any version of external software or internal firmware required to achieve conformance with this International Standard.

NOTE An a.c., d.c. or digital output connection alone is not a display device.

G.3 Vibration sensitivity

The following information shall be given:

a) identification of the vibration calibrator(s) that may be used to establish the vibration sensitivity of the instrument;

b) calibration check frequency, or frequencies;

c) recommended procedures to check and adjust the vibration sensitivity of the instrument at the reference vibration value on the reference measurement range and at the calibration check frequency;

d) indication of the predicted rate of sensitivity drift under normal working conditions;

e) procedure for *in-situ* tests (see Clause 14).

G.4 Sensitivity to variations in environmental conditions

The following information shall be given:

a) procedures for adjusting the result of measurements of the effects of temperature and humidity when these differ from the reference environmental conditions;

b) identification of the components of the vibration meter that conform to applicable specifications of this International Standard for sensitivity to variations in environmental conditions;

c) statement of the typical time interval needed for the vibration meter to stabilize after changes in environmental conditions;

d) description of the effects of electrostatic discharges on the operation of the vibration meter; statement about the degradation or loss, if any, of the performance or function of the vibration meter resulting from exposure to electrostatic discharges; for instruments that require access to points inside the instrument for maintenance by a user, a statement, if needed, prescribing the use of precautions against damage by electrostatic discharges;

e) statement that the instrument conforms to the specification of this International Standard for the required immunity to a.c. power-frequency and radio-frequency fields;

f) operating mode(s) of the instrument, and any connecting devices that have the minimum immunity (i.e. are most sensitive) to a.c. power-frequency and radio-frequency fields;

g) orientation of maximum sensitivity to a.c. power-frequency fields;

h) statement of conformance to the specifications for radio-frequency emission.

G.5 Power supply

The following information shall be given:

a) for instruments powered by internal batteries, recommendations for acceptable battery types, and the nominal duration of continuous operation under reference environmental conditions when full capacity batteries are installed;

b) description of the recommended method to check the condition of the power supplies;

c) for battery-powered instruments, the recommended means for operating the instrument from an external power supply;

d) for instruments that are intended to operate from a public supply of a.c. electrical power, a statement of the nominal voltage and frequency of the supply.

G.6 Vibration transducer

The following information shall be given:

a) frequency response (either an example of a typical response for the accelerometer type, or the actual response of the vibration transducer supplied);

b) vibration transducer mass and the mass of any mounting systems supplied;

c) dimensions of vibration transducers and the mounting system;

d) location of vibration transducer axes with respect to the mounting point;

e) temperature range and temperature sensitivity;

f) sensitivity to electromagnetic fields;

g) acoustic sensitivity;

h) transverse sensitivity;

i) maximum shock acceleration;

j) resonant frequency;

k) ability to resist ingress of moisture or dust.

G.7 Accessories

The following information shall be given:

a) corrections to be applied to the results of measurements made when an optional extension cable is placed between the accelerometer and the other components of the vibration meter;

b) maximum recommended cable length between the accelerometer and the vibration instrument;

c) for an a.c. electrical output, the available range of output voltages, the internal electrical impedance at the output, the recommended range of load impedance, and the tolerance limits on the signals at the output;

d) information concerning the use of the vibration meter when equipped with external filters;

e) information concerning connection of auxiliary devices to the vibration meter and the effects of such auxiliary devices on the electrical characteristics of the instrument;

f) for vibration meters that allow the connection of interface or interconnection cables, recommendations for typical cable lengths and a description of the nature of all devices to which the cables may be attached.

G.8 Operating the instrument

The following information shall be given:

a) duration of the initial time interval after power-on, following which the instrument may be used to measure the value of vibration under prevailing environmental conditions;

b) time interval before a reading is displayed following the completion of a measurement;

c) statement of the minimum and maximum averaging times;

d) description of the procedure to pre-set the integration time intervals;

e) description of the recommended method of transferring or downloading digital data to an external data-storage or display device, and identification of the computer software and hardware to accomplish those tasks;

f) at least for reference environmental conditions, typical indications corresponding to the inherent noise from the combination of a recommended vibration transducer and the other components of the instrument (typical indications shall be provided for all available frequency-weightings as a time-averaged vibration value for a stated integration time).

G.9 Additional information for testing

The following information shall be given:

a) for test procedures not covered by the clauses of this International Standard, recommendations for procedures and methods for conducting tests that demonstrate conformance to the specifications given in this International Standard or the instrument documentation, as appropriate;

b) identification of the reference measurement range and specification of its lower boundary;

c) description of the equivalent electrical impedance of the accelerometer(s); the recommended means for substituting an electrical signal equivalent to the signal from the accelerometer; description of the input facility for electrical signals;

d) statement of the maximum vibration acceleration value at the accelerometer and the maximum peak-to-peak voltage at the electrical input facility;

e) statement of the minimum power-supply voltage that will allow the vibration meter to conform to the specifications of this International Standard;

f) description of the reference orientation for testing the effects of exposure to radio-frequency fields;

g) description of the mode(s) of operation of the vibration meter, and any connection devices, which produce the greatest radio-frequency emissions; list of the configurations of the instrument that produce the same, or lower, radio-frequency emissions;

h) description of the effects of variations in air temperature on vibration sensitivity.

G.10 Supplemental information

In principle, the human-vibration meter could be treated as a black box with well-defined reactions (or grades of immunity) to certain external stimuli. But good technical documentation should also inform the user, calibration and service personnel about what is happening inside the instrument.

Many questions that could arise regarding the use and maintenance of an instrument may be answered by providing a basic description of the techniques used and a block diagram showing the main functional parts or sub-units of the whole instrumentation.

Similarly, it is strongly recommended that information be provided beyond the requirements given in this annex, for example, the following:

a) type of transducer, i.e. the physical effect used for sensing the vibration;

b) physical quantity/parameter used as a signal carrier from the transducer to the instrument if it is an analog transmission by wire; alternatively, the basic parameters of wireless and/or digital transmission;

c) sequence of vector summation and r.m.s. detection, especially in the case of digital signal processing;

d) frequency band of pre-filtering and the type of low-pass (anti-aliasing) and high-pass filters;

e) word length of A/D-conversion and the sampling rate; in cases of down-sampling, the resulting word length and sampling rate after down-sampling, prior to the main signal processing;

f) type of signal processing used for band limiting and weighting, for example

    1) direct processing using analog filters,

    2) direct processing using digital recursive filters (infinite impulse response),

    3) direct processing using digital transversal filters (finite impulse response),

    4) spectrum analysis using digital filters of constant percentage bandwidth (stating type of filter and bandwidth as a fraction of octaves),

    5) spectrum analysis using discrete or fast Fourier transform (stating time-window, overlap, resolution and number of lines), followed by

        — inverse transformation into the time domain after frequency weighting (magnitude and phase), or

        — summation of power over the frequency bands after frequency weighting (magnitude only).

Annex H
(normative)

Phase-response requirements for measurement of non-r.m.s. quantities

H.1 General

Measurement of non-r.m.s. quantities, such as peak values, fourth-power-based quantities (VDV) and the maximum running r.m.s. (MTVV), are sensitive to phase errors. This annex is provided to highlight the potential problems of phase response when processing vibration signals to obtain peak and other non-r.m.s. parameters and to provide tests that allow the assessment of an instrument's phase response.

NOTE The specification in 5.9 defines the design-goal overall response of non-r.m.s parameters to a saw-tooth signal. The actual response to the saw-tooth test is sensitive to phase errors, due to the saw-tooth signal being constructed principally from fundamental and 2nd harmonic signals. However, it does not provide a test of the phase response at all frequencies.

If the vibration meter (including the transducer) is designed according to the complex frequency weighting functions specified in 5.6, the risk of errors caused by phase deviation is relatively low. If the weighting filters are constructed from simple analog filters, the correct phase response is automatically achieved.

Where frequency weighting is performed using digital filters, the correct weighting can be achieved by recursive digital filters with a sufficiently high sample frequency. However, using non-recursive (transversal) digital weighting filters (e.g. zero-phase-shift-filters) or weighting the signal via frequency analysis (band-pass filters or Fourier transform DFT or FFT) can cause considerable errors with non-r.m.s. quantities.

H.2 Definition and evaluation of phase response

H.2.1 General

The design goal for the phase response is defined by Equations (8) to (12) and can be calculated from:

$$\tan(\varphi) = \frac{\mathrm{Im}[H(s)]}{\mathrm{Re}[H(s)]} \tag{H.1}$$

where $H(s)$ is defined by Equation (12). Values for the phase angle φ are included in Tables B.1 to B.9.

The phase response of a human vibration meter shall be compared with the design-goal for phase response. However, the errors caused by phase deviation are not simply related to the simple difference between the instrument response and the design goal; the important factor is how the phase error changes with frequency. For this reason, the parameter characteristic phase deviation ($\Delta\varphi_0$, or CPD) has been defined. It is derived from the difference between the real and ideal phase response functions:

$$\Delta\varphi_0(f) = \left|\Delta\varphi(f) - f \cdot \Delta\varphi'(f)\right| \tag{H.2}$$

where

f is the frequency;

$\Delta\varphi(f)$ is the phase deviation;

$\Delta\varphi'(f)$ is the differential quotient (the slope of the $\Delta\varphi(f)$ curve).

If tolerances were specified for the phase error $\Delta\varphi(f)$, then extremely narrow tolerances would be necessary in order to achieve the specified measurement accuracy for the non-r.m.s. quantities. The conversion into $\Delta\varphi_0(f)$ gives the real phase response much more freedom for the same measurement accuracy.

NOTE 1 A constant group delay time (phase deviation proportional to frequency, i.e. constant slope of response curve) would probably far exceed the tolerances on phase deviation, but would influence neither the vibration parameters to be measured nor the characteristic phase deviation values. On the other hand, a frequency-dependent group delay time (variable slope of response curve) could cause considerable deviations of vibration parameters to be measured without exceeding the tolerances for phase deviation.

In practice, it is sufficient to determine $\Delta\varphi_0(f)$ for a sequence of discrete frequencies f_n, preferably in steps of one-third octave. Equation (H.2) is then approximated by Equation (H.3) [also Equation (13)]

$$\Delta\varphi_0(f_n) = \left| \frac{f_{n+1} \cdot \Delta\varphi(f_n) - f_n \cdot \Delta\varphi(f_{n+1})}{f_{n+1} - f_n} \right| \tag{H.3}$$

This allows the calculation of $\Delta\varphi_0(f_n)$ at each frequency f_n except for the highest frequency.

Recommended characteristic phase deviation tolerances are given in Table 5 and tabulated in Tables B.1 to B.9.

The likely maximum peak value deviation ΔPV_{max} resulting from $\Delta\varphi_0(f)$ may be approximated by the formula:

$$\Delta PV_{max} \approx \pm \max.\{0{,}48 \times \sin[\Delta\varphi_0(f_n)]\} \times 100\ \% \tag{H.4}$$

For the maximum characteristic phase deviations of 12°, the maximum peak value deviation is approximately 10 %.

NOTE 2 Equation (H.4) is an approximation to numerical results and applies to small $\Delta\varphi_0$ values only (< 30°). Depending on the signal waveform, the actual peak value deviation will normally be smaller than ΔPV_{max} which is a worst-case estimate, combining the amplitudes and zero phase angles of two frequency components in the most unfavourable manner. But in the very unlikely case that more components contribute unfavourably, the actual peak value deviation can grow even higher. Statistically, the term “maximum” may be assumed to be a very low percentile. Although this method has been developed originally for peak value measurements, it can also be used as a first estimate for VDV measurements.

Two procedures are defined in this annex which provide methods for testing directly or indirectly the characteristic phase deviation. The first test procedure presumes that the frequency-weighted signal (analog or digital) is available just before extracting the signal parameters, so that no further phase shift in the signal path can occur. If this signal is not accessible but a peak measuring mode is incorporated, the second two-tone procedure is recommended.

H.2.2 Testing phase response directly

If the frequency-weighted signal (analog or digital) is available just before extracting the signal parameters (so that no further phase shift in the signal path can occur), tests of the phase response of a vibration measuring instrumentation can be performed according to ISO 16063-21 (comparison method) using a reference vibration transducer with calibrated phase response. The phase response calibration of the reference transducer can be performed according to ISO 16063-11 (laser interferometry) or ISO 16063-12 (reciprocity method).

H.2.3 Testing phase response by the two-tone method

H.2.3.1 Conditions for the two-tone test

If the frequency-weighted signal is not accessible before extracting the signal parameters, but a peak measuring mode is incorporated, it is recommended that the phase response be measured indirectly using a two-tone method.

H.2.3.2 Principle of the two-tone test

Two harmonic vibrations with parameters f_{fu}, r_{fu}, φ_{fu} and f_{ha}, r_{ha}, φ_{ha} (where f is the frequency, r is the r.m.s. value, φ is the zero-phase angle of sine function; subscript fu indicates fundamental, and ha indicates harmonic) are superimposed and applied by a shaker to the vibration meter under test. The values of f_{fu}, r_{fu}, f_{ha}, r_{ha} are chosen such that the PEAK value displayed is most sensitive to a small unwanted phase shift in the signal path. This is the case for

$f_{fu} / f_{ha} = 3$ and $r_{fu} / r_{ha} = 3$

When varying the zero-phase angle of the harmonic, φ_{ha}, the PEAK value goes through a relatively sharp minimum at

$\varphi_{ha} = 3\ \varphi_{fu}$

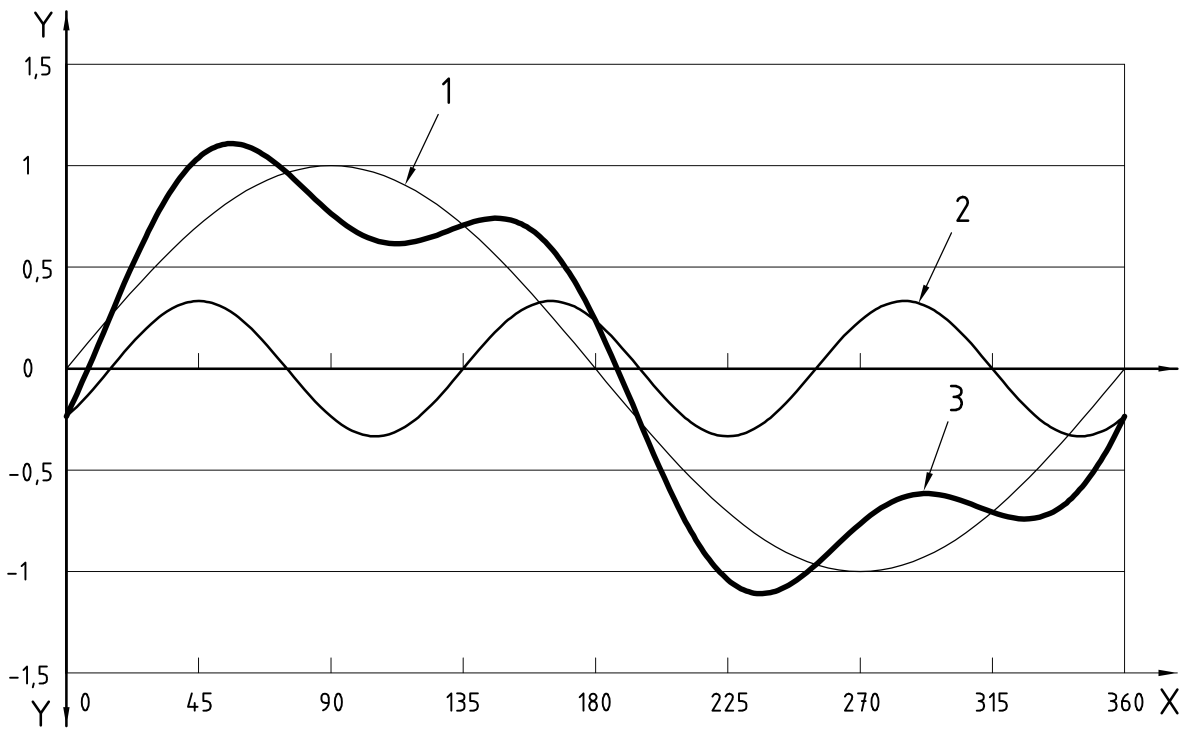
where two humps of the curve change their role as the highest one. This point has to be found by means of a phase-shifting device and the display of the human-vibration meter itself.

Near the minimum, the differential error of the PEAK values approaches its absolute maximum with 1,75 % per degree. The minimum PEAK value itself is equal to

$0{,}943\ r_{fu}$

Figure H.1 shows the signal waveform with $\varphi_{ha} = 15°$ and $\varphi_{fu} = 0°$, and Figure H.2 shows the PEAK value versus φ_{ha} with $\varphi_{fu} = 0$.

The method also gives an impression of the span of PEAK value errors due to phase shift in this special case. With arbitrary signals, the effect can be smaller (other ratios of amplitude and/or frequency) or higher (sharp edged signals or short impulses).



Key

X phase of fundamental (degrees)

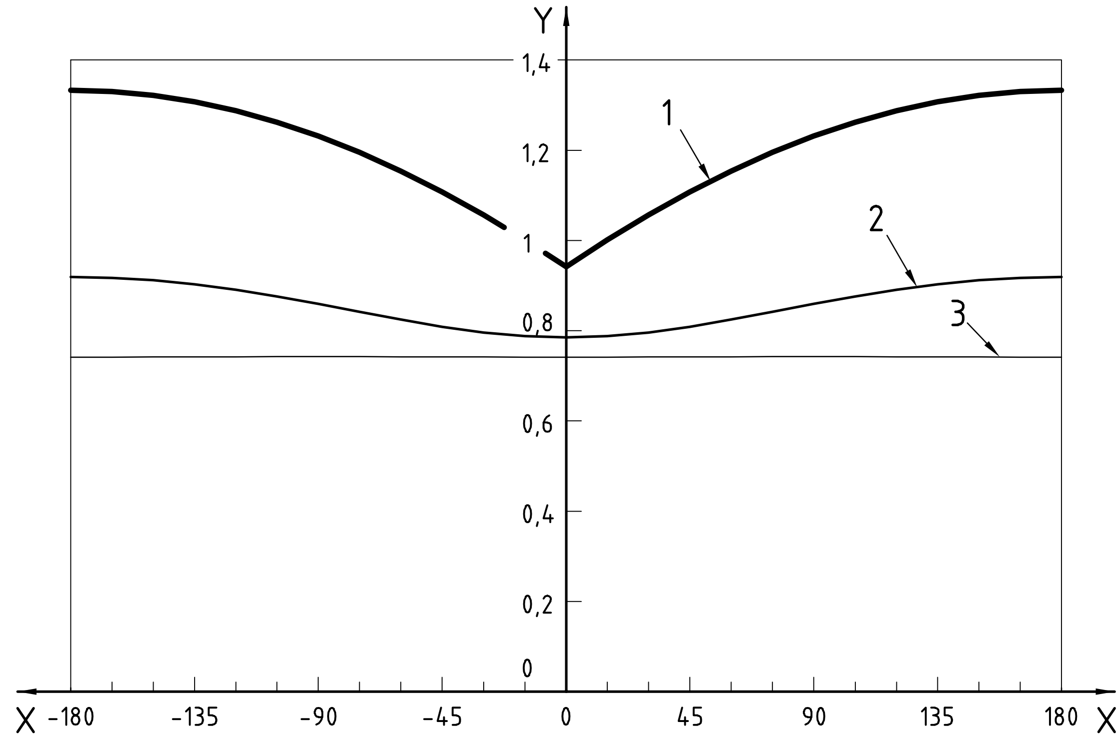
Y waveform magnitude

1 fundamental

2 harmonic (15° shift)

3 resultant

Figure H.1 — Graph of functions



Key

X phase shift of harmonic signal (degrees)

Y vibration value

1 max. peak, m/s^2

2 VDV, $m/s^{1,75}$

3 r.m.s., m/s^2

Figure H.2 — PEAK and VDV values versus phase-shift of harmonic
(Constant amplitudes of fundamental and harmonic sine waves)

H.2.3.3 Equipment needed

Most of the equipment required for the two-tone method is equipment that will be available in laboratories equipped to perform frequency response calibration, as follows:

a) a two-tone generator/oscillator, providing harmonically related outputs (as a minimum providing a frequency ratio of 1:3) or a single-tone generator plus a frequency multiplier or divider;

b) if the generator does not provide controllable amplitudes and zero phase angles, then the following are also required:

— two amplitude controllers (variable amplifiers or attenuators, possibly combined as a mixing console), and

— a phase shift controller (phase bridge, delay line);

c) a signal mixer (summing amplifier or mixing console) if it is not part of other equipment;

d) a vibration exciter (shaker) with power amplifier;

e) a reference vibration transducer, calibrated by amplitude and phase response;

f) a phase meter capable of measuring phase shift or phase delay time between harmonically related sine signals;

g) the human-vibration meter to be tested.

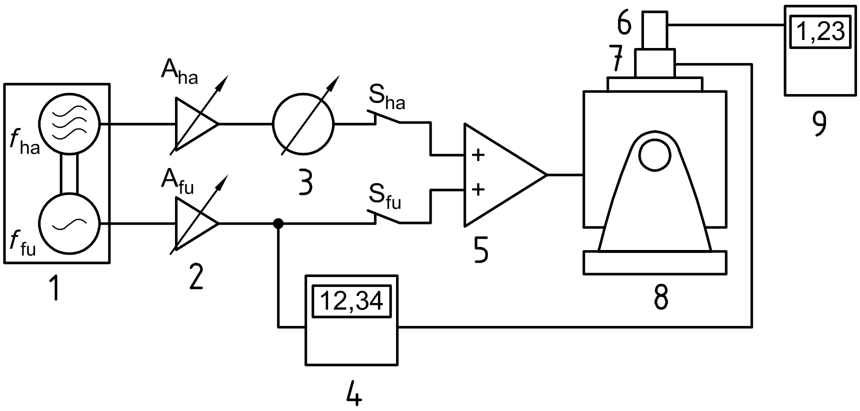
Recommended additionally are

h) an FFT analyser, and

i) an oscilloscope.

A block diagram of the total test installation is shown in Figure H.3.

The method is described by the following operation instruction. It is recommended that PC-controllable instruments be used, in order to automate the procedure.



Key

1 two-tone phase-coupled signal generator
2 amplitude controllers
3 phase shifter
4 phase meter
5 summing and power amplifier
6 HVM transducer
7 reference transducer
8 vibration exciter
9 human-vibration meter (HVM)

Figure H.3 — Block diagram of two-tone method

H.2.3.4 Test procedure

With the human-vibration meter (HVM) set to indicate the PEAK value of the frequency-weighted vibration, proceed as follows.

a) Adjust the signal generator frequencies to be in the mid-range of the frequency range to be tested (e.g. for whole-body vibration, set f_{fu} to 9 Hz and f_{ha} to 27 Hz).

b) With switch S_{fu} on and switch S_{ha} off, adjust the amplitude controller A_{fu} to give a suitable indication on the HVM for $a_{peak,fu}$ (e.g. 60 % of full scale). Read from the phase meter ϕ_{fu}.

c) With switch S_{fu} off and switch S_{ha} on, adjust the amplitude controller A_{ha} in such way that the indication of HVM $a_{peak,ha}$ is equal to one third of $a_{peak,fu}$; i.e. $a_{peak,ha} = a_{peak,fu}/3$.

Adjust the phase shifter so that the indication of the phase meter (in terms of f_{fu}) is principally the same as in step b), but corrected for the different phase delay times of the reference transducer; the phase meter will then indicate (in terms of f_{fu}):

$$\phi_{ha} = \phi_{fu} - \phi_{tr,fu} + \phi_{tr,ha} \frac{f_{ha}}{f_{fu}}$$

where

$\phi_{tr,fu}$ is the phase shift of reference transducer at f_{fu};

$\phi_{tr,ha}$ is the phase shift of reference transducer at f_{ha};

f_{ha} / f_{fu} is the factor transforming $\phi_{tr,ha}$ in terms of f_{fu}.

This adjustment will produce equal zero-phase angles of the vibration on the shaker table when both signals are superimposed.

NOTE 1 It is assumed that the phase shift is displayed in terms of the lower frequency. Therefore $\phi_{tr,ha}$ has to be transformed by the factor f_{ha} / f_{fu}. Alternatively all phase quantities could be transformed into phase delay times (division by $2\pi f$) in order to compare or combine them. In this case, the phase meter should be switched to display the phase delay times directly.

NOTE 2 The control device for phase shift can influence the amplitude and vice versa. Check this by going back and forth, and re-adjust if necessary. Moderate changes of amplitude will have little effect on the phase measurements.

d) With both switches S_{fu} and S_{ha} on, adjust the phase shifter for minimum PEAK indication of the HVM.

This means that the fundamental and the harmonic at the PEAK detector of the HVM have equal zero-phase angles; i.e. they are in phase.

To check the amplitudes, read the indication of the HVM; it should be equal to 0,943 r_{fu}. Shift the phase to maximum indication of the HVM, it should be equal to 1,333 r_{fu}. Go back to minimum indication.

e) With switch S_{fu} off and switch S_{ha} on, read from the phase meter ϕ_{ha+}. Calculate the additional phase shift put on the phase shifter at step d), i.e. the difference:

$\Delta\phi = \phi_{ha+} - \phi_{ha}$ [ϕ_{ha} from step c), ϕ_{ha+} from step e), both in terms of f_{fu}].

Calculate the corresponding difference of phase delay time:

$$\Delta\theta = \frac{\Delta\phi}{2\pi f_{fu}}$$

This is equal to the difference between the inherent phase delay times of the HVM at f_{ha} and f_{fu}.

f) Change both frequencies by a factor 3 up or down and repeat steps b) to e) until the whole frequency range specified in this International Standard is covered by pairs of frequencies (e.g. for whole-body vibration: 1 Hz / 3 Hz, 3 Hz / 9 Hz, 9 Hz / 27 Hz, 27 Hz / 81 Hz.)

g) Accumulate the respective phase delay time differences $\Delta\theta$, beginning with the lowest frequency. The resulting sequence of accumulated phase delay time differences versus frequency will represent discrete samples of the continuous function (curve), except for an unknown constant delay time, equal for each sample.

h) In order to gain intermediate samples, change both frequencies by a factor $3^{0,2}$ (equivalent to 95 % of one-third octave) up or down and repeat steps b) to g).

i) Repeat step h) four times, every time ending with a new sequence of samples. Join all five sequences to a large one, the frequencies of which will be equidistant on a logarithmic scale. The associated phase delay times drawn as ordinates on a logarithmic scale too, will show heavy oscillations, resulting from the unknown constant delay times for each of the original sequences.

j) Smooth the curve (the function), i.e. align the sequences of samples for best fit by adjusting the constant delay times one after another by a suitable procedure. This may be done graphically or numerically, e.g. by iteration, minimizing the length of a polygonal curve connecting all contiguous sample-points of a pair of sequences in a double logarithmic scale.

k) Calculate the theoretical frequency response function of the phase delay time versus the frequency of the HVM from the design goal phase shifts specified in this International Standard; i.e. divide the values in degrees by $-(360° \times$ frequency). Before dividing, the phase shift has to be reduced by 180° (corresponds to signal inversion) in order to avoid negative phase delay times.

   This corresponds to the main branches of the arctan functions, whereas in Tables B.1 to B.9 and in the corresponding diagrams Figures B.2 to B.18 (even numbers only) 180° have been added.

   NOTE The 180° phase shift of all frequency components leaves the wave form of the signal unchanged, but would create catastrophic results attempting to apply the CPD criterion. This is not a contradiction. For the CPD criterion has been introduced only to assess unintentional deviations of the phase response from its design goal, it is not applicable for signal inversion. Signal inversion is a unique form of signal processing which needs its own test procedure, the polarity test, in cases where the direction of vibration is important for the result (e.g. +peak, −peak, shock response spectra). This is not the case with this International Standard.

l) Align the combined sequence of all samples gained experimentally as well as possible with the graph of the theoretical function according to step k) by adjusting the remaining constant delay of experimental data, as in step j).

   This will be relatively simple if the phase response has a natural behaviour. In this case, the curve in a double logarithmic diagram will be relatively linear over a wide frequency range. This is true for all weighting functions defined in this International Standard.

m) Transform the frequency response function of the phase delay time of the HVM, aligned according to step l), back to phase domain (multiplication by $360° \times$ frequency), yielding the frequency response function of the phase shift.

n) Apply the CPD criterion (as defined in H.2.1) to the frequency response function of the phase shift found by step m). The CPD criterion is invariant with respect to delay time. Therefore any remaining constant delay time (except 180°) will not influence the result at all.

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ICS 13.160

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