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Human response to vibration — Measuring instrumentation

Réponse des individus aux vibrations — Appareillage de mesure

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 8041 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock.*

Annexes A to D form an integral part of this International Standard.

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Introduction

Owing to the complexity of the human sensation of vibration it is not possible at present to design an objective vibration-measuring apparatus to give results which are absolutely comparable, for all types of vibration, with those observed by human beings. It is, however, considered essential to standardize instrumentation by which vibration can be measured under closely defined conditions so that results obtained by users of such instrumentation are always the same within stated tolerances. The instrumentation specified in this International Standard covers the need for at least one of the methods of measurement according to ISO 2631 and ISO 5349.

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Human response to vibration — Measuring instrumentation

1 Scope

This International Standard specifies instrumentation for a method of measurement of vibration in a given frequency range, given in ISO 2631-1 for assessing the vibration as perceived by human beings. It applies to instrumentation for the measurement of hand-arm vibration and/or whole-body vibration. For other methods of measurement, ISO 2631 and ISO 5349 should be consulted.

This International Standard specifies electrical, vibration and environmental tests to verify compliance with the characteristics specified (see clause 4). It also determines the method for sensitivity calibration.

The purpose of this International Standard is to ensure consistency and compatibility of results and reproducibility of measurements realized with different measuring instrumentation using this method of measurement.

An instrument or an instrument collection may be realized which fulfils only the necessary requirements for measurement of hand-arm or whole-body vibrations under certain conditions, for example in the z direction, provided that the purpose is clearly stated and pertinent requirements of this International Standard are fulfilled.

In conjunction with spectral analysis, proper filter characteristics shall be applied (see clause 4).

2 Normative references

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

ISO 266 : 1975, *Acoustics — Preferred frequencies for measurements.*

ISO 1683 : 1983, *Acoustics — Preferred reference quantities for acoustic levels.*

ISO 2041 : — [1], *Vibration and shock — Vocabulary.*

ISO 2631-1 : 1985, *Evaluation of human exposure to whole-body vibration — Part 1: General requirements.*

ISO 2631-2 : 1989, *Evaluation of human exposure to whole-body vibration — Part 2: Continuous and shock-induced vibrations in buildings (*1 to 80 Hz*).*

ISO 2631-3 : 1985, *Evaluation of human exposure to whole-body vibration — Part 3: Evaluation of exposure to whole-body z-axis vertical vibration in the frequency range* 0,1 *to* 0,63 Hz.

ISO 5347-0 : 1987, *Methods for the calibration of vibration and shock pick-ups — Part 0: Basic concepts.*

ISO 5348 : 1987, *Mechanical vibration and shock — Mechanical mounting of accelerometers.*

ISO 5349 : 1986, *Mechanical vibration — Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration.*

ISO 5805 : 1981, *Mechanical vibration and shock affecting man — Vocabulary.*

ISO 8042 : 1988, *Shock and vibration measurements — Characteristics to be specified for seismic pick-ups.*

IEC 225 : 1966, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 2041 and ISO 5805, together with the following, apply.

3.1 weighted vibration: Frequency-weighted overall r.m.s. acceleration. It is expressed in metres per second squared. Alternatively, instrumentation may express results in metres per second squared and as a level in decibels. The level in decibels is 20 times the logarithm to the base 10 of the ratio of a weighted acceleration, expressed in metres per second squared, to the reference acceleration.

1) To be published. (Revision of ISO 2041 : 1975.)

The acceleration is weighted in accordance with one of the five frequency weightings listed in table 1 and specified in tables 4 to 8.

Table 1 — Frequency ranges

Characteristics of vibration	Frequency range Hz	International Standard
Whole body, severe discomfort, z: designated W.B.S.D.z	0,1 to 1	ISO 2631-3
Whole body, x-y: designated W.B.x-y	1 to 80	ISO 2631-1
Whole body, z: designated W.B.z	1 to 80	ISO 2631-1
Whole body, combined: designated W.B.combined	1 to 80	ISO 2631-2
Hand-arm: designated H.-A.	8 to 1 000	ISO 5349

The acceleration is time-weighted using exponential averaging (see clause A.3 and annex D) with specified time constants, and peak or integrated mean-square values over a specified time period. When quoting the weighted acceleration, the frequency weighting and linear or exponential time-weighting shall be indicated.

NOTE — The term "weighted vibration" is often replaced by "weighted acceleration" or "vibration". Whenever a velocity transducer or displacement transducer is used, the weighting applied should be changed accordingly. The type of transducer used should always be reported.

3.2 reference acceleration: The acceleration for expressing vibration levels given in ISO 1683 as 10^{-6} m/s^2.

If a different reference acceleration is used, this shall be stated.

3.3 equivalent continuous vibration value and level

3.3.1 equivalent continuous vibration value: The equivalent continuous weighted acceleration, $a_{\mathrm{w\,eq}}$, defined by the r.m.s. value:

$$a_{\mathrm{w\,eq}} = \left\{ \frac{1}{T_\mathrm{m}} \int_0^{T_\mathrm{m}} [a_\mathrm{w}(t)]^2 \, \mathrm{d}t \right\}^{1/2} \qquad \ldots (1)$$

where

$a_\mathrm{w}(t)$ is the instantaneous weighted acceleration, in metres per second squared;

T_m is the integration time interval, in seconds;

t is the time, in seconds.

3.3.2 equivalent continuous vibration level: The equivalent continuous weighted acceleration level, $L_{\mathrm{w\,eq}}$, in decibels, defined by

$$L_{\mathrm{w\,eq}} = 10 \lg \left\{ \frac{1}{T_\mathrm{m}} \int_0^{T_\mathrm{m}} \frac{[a_\mathrm{w}(t)]^2}{a_0^2} \, \mathrm{d}t \right\} \qquad \ldots (2)$$

where

a_0 is the reference acceleration ($a_0 = 10^{-6}$ m/s^2);

$a_\mathrm{w}(t)$, T_m and t are as defined in 3.3.1.

The integration time interval shall always be specified.

3.4 crest factor: The ratio of the peak signal value evaluated over a specified time interval to the r.m.s. value over the same time interval.

NOTE — It is recommended that the r.m.s. value of the signal be measured using 60 s linear integration.

3.5 signal

3.5.1 pulse duty factor: For a rectangular sequence, the ratio between the pulse duration and the repetition period of the signal.

3.5.2 signal burst: One or more complete cycles of sinusoidal signal; for the purpose of this International Standard, the signal burst starts and ends at a zero crossing of the waveform.

3.5.3 burst duty factor: For a sequence of signal bursts, the ratio between the burst duration and the repetition period of the signal.

3.6 primary indicator range: A specified range of the indicator of a vibration-measuring instrumentation for which the vibration-measuring instrumentation readings are within particularly close tolerances on sensitivity linearity as specified in 6.7.

3.7 sensitivity linearity: The term indicating that the reading of the vibration-measuring instrumentation is proportional to the magnitude of the input signal, within stated tolerances.

3.8 reference calibration frequency: The frequency, specified by the manufacturer, used for calibration of the sensitivity of vibration-measuring instrumentation. Preferred reference calibration frequencies are given in table 2.

Table 2 — Preferred reference calibration frequencies

Characteristics of vibration	Reference calibration frequency ω s^{-1}	Reference calibration frequency f Hz	Weighting factor	
Whole body, severe discomfort, z	2,5	0,398	0,666	(−3,53 dB)
Whole body, x-y	50	7,96	0,254	(−11,91 dB)
Whole body, z	50	7,96	0,905	(−0,87 dB)
Whole body, combined	50	7,96	0,581	(−4,71 dB)
Hand-arm	500	79,6	0,202	(−13,89 dB)

3.9 reference calibration acceleration: An acceleration, specified by the manufacturer, used for calibrating the sensitivity of the vibration-measuring instrumentation.

NOTE — A reference calibration acceleration of 1 m/s^2 is preferred at 8 Hz, 80 Hz or 160 Hz. At 0,4 Hz a reference calibration acceleration of 0,1 m/s^2 is preferred.

4 Characteristics

Vibration-measuring instrumentation is generally a combination of a vibration transducer, an amplifier with a specified frequency weighting, and a detector-averager-indicator device with controlled characteristics. In clauses 5 and 6 specifications are given for these parts of the vibration-measuring instrumentation and tolerances are given for two types of vibration-measuring instrumentation. Any additional items (such as connectors, cables and preamplifiers) are regarded as integral parts of the vibration-measuring instrumentation. The manufacturer shall specify the connecting cable for which the calibration is valid. For instructions concerning mounting and calibration of transducers, see ISO 5348 and ISO 5347-0 respectively.

NOTE — This International Standard does not state a preference for either analogue or digital signal processing. Both techniques are compatible with this International Standard as long as the requirements are complied with.

The specified characteristics of measuring instrumentation considered in this International Standard are as follows:

a) frequency-weighting characteristics;

b) bandlimiting;

c) time-weighting, detector and indicator characteristics;

d) sensitivity to various environments.

The instrumentation specified in this International Standard may also be used for spectral analysis. In this case, filter characteristics shall comply with IEC 225.

4.1 Tolerances

The specifications given for type 1 and type 2 vibration-measuring instrumentation have the same nominal value and differ mainly in the tolerances allowed. Tolerances are generally tighter for type 1 than for type 2 instrumentation and differ for the two types to a degree which affects the manufacturing costs significantly.

4.2 Applications

Type 1 instrumentation is intended especially for use where the vibration environment can be closely specified and/or controlled, and where certain specifications are to be evaluated or met. The measurement accuracy possible with such an instrument will generally not be realized under ordinary conditions. Type 2 instrumentation is suitable for general applications.

4.3 Weighting characteristics

4.3.1 Frequency weighting

Human-response vibration-measuring instrumentation shall have one or more frequency-weighting characteristics designated as follows (for an explanation of the abbreviations, see table 1): 0,1 Hz to 1 Hz (W.B.S.D.*z*); 1 Hz to 80 Hz (W.B.*x-y* and W.B.*z*); 1 Hz to 80 Hz (W.B.combined); 8 Hz to 1 000 Hz (H.-A.). Other optional weighting characteristics may be included.

If such optional weighting characteristic is designated "flat", its frequency response with respect to the input signal, for example acceleration or velocity, shall be constant but imposed by the appropriate band limiting characteristic. A flat characteristic enables the instrumentation to function as a preamplifier for an auxiliary device or to measure the unweighted signal.

Weighting and amplifier circuits shall satisfy the requirements of 5.1. When the flat response is provided, the manufacturer shall specify its frequency range and tolerances. The tolerances shall not be greater than those for the frequency-weighting characteristics (tables 4 to 8).

4.3.2 Time weighting

Human-response vibration-measuring instrumentation shall have at least

a) a 1 s exponential averaging time constant;

b) a linear integrated mean-square value over 60 s or more.

If it includes additional time constants, these should preferably be 1/8 s or 8 s.

When provided, the peak characteristic allows the vibration-measuring instrumentation to indicate the maximum peak of the vibratory signal whether it is positive or negative.

The linear integrated mean square value can also be evaluated from the exponentially averaged signal in good approximation. In this case, the manufacturer shall specify the time constant used.

NOTE — The integration times specified should not be taken to be necessarily representative of an integration time of the human body.

4.4 Indication under reference conditions

The indication of the vibration-measuring instrumentation under the reference conditions as defined in 3.8, 3.9, 7.3 and 7.4 shall be accurate within 8 % ($\pm$0,7 dB) and $^{+12\%}_{-11\%}$ ($\pm$1 dB) for type 1 and type 2 instrumentation respectively after any warm-up period specified by the manufacturer. A means shall be available to check and maintain calibration at the reference frequency. This may be fulfilled by proper recommendations given in the manufacturer's instructions for use.

4.5 Battery-operated instrumentation

If the vibration-measuring instrumentation is battery operated, suitable means shall be provided to check that the battery voltage and stability is adequate to operate the instrumentation within its specifications.

4.6 Maximum change in reading

After a warm-up period, to be specified by the manufacturer but to be less than 10 min in duration, the reading shall not change within 1 h of continuous operation under constant test conditions by more than the value shown in table 3.

Table 3 — Maximum change in reading within 1 h of operation

Type 1		Type 2	
%	dB	%	dB
3,5	0,3	6	0,5

4.7 Sensitivity axis of the vibration transducer

The manufacturer shall specify the main axis of sensitivity and the transverse sensitivity. Additionally, information shall be given regarding the amount of simultaneous transverse vibration allowed in order to maintain the stated main axis sensitivity at the specified value ±6 % (±0,5 dB).

5 Frequency-weighting and amplifier characteristics

5.1 General

The complete instrumentation comprising the transducer, amplifier, weighting network and detector-indicator shall have one or more of the characteristics and tolerances given in tables 4 to 8 (corresponding graphs and analytical expressions are given for information in annex B and annex C respectively). Provisions for external filter connection may be included.

5.2 Sensitivity or level-range control

When a sensitivity or level-range control is included it shall not introduce errors greater than ±3,5 % (±0,3 dB) for type 1 and ±6 % (±0,5 dB) for type 2 instrumentation for all settings and frequencies in the working range with reference to a range setting specified by the manufacturer. The reference range shall include the calibration vibration defined in 3.9 and the above tolerances shall be verified on the basis of this level.

5.3 Manual sensitivity or level-range control

When a manual sensitivity or level-range control is included in a vibration-measuring instrumentation, the primary indicator ranges shall overlap by at least a factor of 0,6 (5 dB) if the step of the range control is 10 dB and by at least a factor of 0,3 (10 dB) if the step of the range control is greater.

5.4 Peak-handling capacity

The amplifier shall have a peak-handling capacity sufficient to meet the requirements of 6.2.

If an automatic range control system is used, its settling time shall be specified.

5.5 Overload indicator

Overload detectors shall, where necessary, be placed in the amplifier chain and shall indicate when the peak-handling capacity has been exceeded. If overload can cause erroneous readings, this shall be indicated.

For the linear-integration facility of the instrumentation a latching overload indicator shall be provided.

5.6 Signal-to-noise ratio

The maximum level of internal noise on any measurement range shall be at least a factor of 1,8 (5 dB) below the specified minimum vibration measurable on that range. A test for verifying the signal-to-noise ratio is given in 8.6.

5.7 Properties of electrical output

In cases where output terminals are provided to monitor signal waveforms, the instrumentation shall not introduce more than 2 % distortion when the test signal is not more than a factor of 0,3 (10 dB) below the equivalent upper limit of the weighted vibration magnitude which the instrumentation is designed to measure.

At the upper limit of vibration, to be stated by the manufacturer, the total harmonic distortion generated between the vibratory input and the signal output, where the latter is provided, shall be less than 10 % at any frequency for that range.

For all frequency weightings, at the upper limit of each primary indicator range, the manufacturer shall state the frequency range for which the error resulting from non-linear distortion generated between the vibratory input and the signal output is less than ${}^{+12\%}_{-11\%}$ (±1 dB).

6 Detector and indicator characteristics

6.1 Instrumentation indication

The indication of the vibration-measuring instrumentation with any detector-indicator characteristics in operation shall be the r.m.s. and, if included, the peak value of the signal, the time constant or integration time being specified.

Table 4 — Frequency weighting: whole body, severe discomfort, *z* axis, 0,1 Hz to 1 Hz (motion sickness), based on ISO 2631-3

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
0,01	0,010 0	1 000	15,85	+26 —	0,00	−36,00	+2 —
0,012 5	0,012 5	1 000	25,12	+26 —	0,00	−32,00	+2 —
0,016	0,015 8	1 001	39,80	+26 —	+0,01	−28,00	+2 —
0,02	0,019 9	1 001	63,03	+26 —	+0,01	−24,01	+2 —
0,025	0,025 1	1 001	99,65	+26 —	+0,01	−20,03	+2 —
0,031 5	0,031 6	1 002	156,9	+26 —	+0,02	−16,09	+2 —
0,04	0,039 8	1 004	244,5	+26 —	+0,03	−12,23	+2 —
0,05	0,050 1	1 006	372,0	+26 −21	+0,05	−8,59	±2
0,063	0,063 1	1 009	538,3	+26 −21	+0,08	−5,38	±2
0,08	0,079 4	1 014	716,6	+26 −21	+0,12	−2,89	±2
0,1	0,100 0	1 020	862,6	+26 −21	+0,17	−1,28	±2
0,125	0,125 9	1 029	955,3	+12 −11	+0,24	−0,40	±1
0,16	0,158 5	1 036	1 004	+12 −11	+0,31	+0,04	±1
0,2	0,199 5	1 033	1 019	+12 −11	+0,28	+0,16	±1
0,25	0,251 2	994,5	984,6	+12 −11	−0,05	−0,13	±1
0,315	0,316 2	880,1	867,5	+12 −11	−1,11	−1,23	±1
0,4	0,398 1	686,6	665,4	0	−3,27	−3,54	0
0,5	0,501 2	480,3	446,1	+12 −11	−6,37	−7,01	±1
0,63	0,631 0	318,5	269,4	+26 −21	−9,94	−11,39	±2
0,8	0,794 3	209,3	148,0	+26 −21	−13,59	−16,60	±2
1	1,000	139,2	74,27	+26 −21	−17,13	−22,58	±2
1,25	1,259	94,67	35,02	+26 −21	−20,48	−29,11	±2
1,6	1,585	66,15	16,12	+26 —	−23,59	−35,86	+2 —
2	1,995	47,52	7,439	+26 —	−26,46	−42,57	+2 —
2,5	2,512	35,03	3,485	+26 —	−29,11	−49,16	+2 —
3,15	3,162	26,38	1,661	+26 —	−31,58	−55,59	+2 —
4	3,981	20,20	0,803 4	+26 —	−33,89	−61,90	+2 —
5	5,012	15,65	0,393 1	+26 —	−36,11	−68,11	+2 —
6,3	6,310	12,24	0,193 9	+26 —	−38,25	−74,25	+2 —

1) Preferred frequencies according to ISO 266.

Table 5 — Frequency weighting: whole body, *x* axis and *y* axis, 1 Hz to 80 Hz, based on ISO 2631

Frequency, Hz		Weighting factor (values stated $\times 10^{-3}$)		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
0,1	0,100 0	1 001	15,86	+26 —	+0,01	−36,00	+2 —
0,125	0,125 9	1 001	25,14	+26 —	+0,01	−31,99	+2 —
0,16	0,158 5	1 002	39,85	+26 —	+0,02	−27,99	+2 —
0,2	0,199 5	1 003	63,14	+26 —	+0,02	−23,99	+2 —
0,25	0,251 2	1 004	99,93	+26 —	+0,04	−20,01	+2 —
0,315	0,316 2	1 007	157,6	+26 —	+0,06	−16,05	+2 —
0,4	0,398 1	1 010	246,1	+26 —	+0,09	−12,18	+2 —
0,5	0,501 2	1 015	375,5	+26 −21	+0,13	−8,51	±2
0,63	0,631 0	1 022	545,1	+26 −21	+0,19	−5,27	±2
0,8	0,794 3	1 029	727,3	+26 −21	+0,25	−2,77	±2
1	1,000	1 032	873,1	+26 −21	+0,28	−1,18	±2
1,25	1,259	1 023	950,8	+12 −11	+0,20	−0,44	±1
1,6	1,585	985,6	955,9	+12 −11	−0,13	−0,39	±1
2	1,995	903,8	892,6	+12 −11	−0,88	−0,99	±1
2,5	2,512	781,7	777,8	+12 −11	−2,14	−2,18	±1
3,15	3,162	644,2	642,9	+12 −11	−3,82	−3,84	±1
4	3,981	515,9	515,5	+12 −11	−5,75	−5,76	±1
5	5,012	408,2	408,1	+12 −11	−7,78	−7,78	±1
6,3	6,310	322,1	322,0	+12 −11	−9,84	−9,84	±1
8	7,943	254,2	254,2	0	−11,90	−11,90	0
10	10,00	200,9	200,9	+12 −11	−13,94	−13,94	±1
12,5	12,59	159,1	159,0	+12 −11	−15,97	−15,97	±1
16	15,85	126,1	126,0	+12 −11	−17,99	−17,99	±1
20	19,95	99,98	99,90	+12 −11	−20,00	−20,01	±1
25	25,12	79,34	79,18	+12 −11	−22,01	−22,03	±1
31,5	31,62	62,98	62,67	+12 −11	−24,02	−24,06	±1
40	39,81	50,01	49,39	+12 −11	−26,02	−26,13	±1

Table 5 (*concluded*)

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
50	50,12	39,71	38,52	+12 −11	−28,02	−28,29	±1
63	63,10	31,54	29,30	+12 −11	−30,02	−30,66	±1
80	79,43	25,05	21,19	+26 −21	−32,02	−33,48	±2
100	100,0	19,90	14,07	+26 −21	−34,02	−37,03	±2
125	125,9	15,80	8,433	+26 −21	−36,02	−41,48	±2
160	158,5	12,55	4,643	+26 −21	−38,03	−46,66	±2
200	199,5	9,971	2,429	+26 —	−40,03	−52,29	+2 —
250	251,2	7,920	1,240	+26 —	−42,03	−58,13	+2 —
315	316,2	6,291	0,626 0	+26 —	−44,03	−64,07	+2 —
400	398,1	4,997	0,314 7	+26 —	−46,03	−70,04	+2 —
500	501,2	3,969	0,157 9	+26 —	−48,03	−76,03	+2 —
630	631,0	3,153	0,079 1	+26 —	−50,03	−82,03	+2 —
800	794,3	2,505	0,039 6	+26 —	−52,03	−88,03	+2 —

1) Preferred frequencies according to ISO 266.

Table 6 — Frequency weighting: whole body, *z* axis, 1 Hz to 80 Hz, based on ISO 2631

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
0,1	0,100 0	420,9	6,671	+26 —	−7,52	−43,52	+2 —
0,125	0,125 9	421,5	10,58	+26 —	−7,50	−39,51	+2 —
0,16	0,158 5	422,4	16,80	+26 —	−7,49	−35,49	+2 —
0,2	0,199 5	423,7	26,68	+26 —	−7,46	−31,48	+2 —
0,25	0,251 2	425,9	42,38	+26 —	−7,41	−27,46	+2 —
0,315	0,316 2	429,3	67,20	+26 —	−7,34	−23,45	+2 —
0,4	0,398 1	434,6	105,9	+26 —	−7,24	−19,50	+2 —
0,5	0,501 2	442,9	163,8	+26 −21	−7,07	−15,71	±2
0,63	0,631 0	455,8	243,2	+26 −21	−6,82	−12,28	±2

Table 6 (*concluded*)

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
0,8	0,794 3	475,4	336,1	+26 −21	−6,46	−9,47	±2
1	1,000	504,6	426,8	+26 −21	−5,94	−7,40	±2
1,25	1,259	547,4	508,5	+12 −11	−5,23	−5,87	±1
1,6	1,585	607,7	589,4	+12 −11	−4,33	−4,59	±1
2	1,995	689,2	680,7	+12 −11	−3,23	−3,34	±1
2,5	2,512	792,4	788,5	+12 −11	−2,02	−2,06	±1
3,15	3,162	909,4	907,6	+12 −11	−0,82	−0,84	±1
4	3,981	1 015	1 014	+12 −11	+0,13	+0,12	±1
5	5,012	1 064	1 063	+12 −11	+0,53	+0,53	±1
6,3	6,310	1 022	1 022	+12 −11	+0,19	+0,19	±1
8	7,943	905,7	905,6	0	−0,86	−0,86	0
10	10,00	759,6	759,5	+12 −11	−2,39	−2,39	±1
12,5	12,59	618,7	618,6	+12 −11	−4,17	−4,17	±1
16	15,85	497,0	496,9	+12 −11	−6,07	−6,08	±1
20	19,95	396,8	396,5	+12 −11	−8,03	−8,03	±1
25	25,12	316,0	315,4	+12 −11	−10,01	−10,02	±1
31,5	31,62	251,3	250,0	+12 −11	−12,00	−12,04	±1
40	39,81	199,7	197,3	+12 −11	−13,99	−14,10	±1
50	50,12	158,7	153,9	+12 −11	−15,99	−16,25	±1
63	63,10	126,1	117,1	+12 −11	−17,99	−18,63	±1
80	79,43	100,2	84,71	+26 −21	−19,99	−21,44	±2
100	100,0	79,57	56,26	+26 −21	−21,99	−25,00	±2
125	125,9	63,21	33,73	+26 −21	−23,98	−29,44	±2
160	158,5	50,21	18,57	+26 −21	−25,98	−34,62	±2
200	199,5	39,88	9,716	+26 —	−27,98	−40,25	+2 —
250	251,2	31,68	4,959	+26 —	−29,98	−46,09	+2 —
315	316,2	25,16	2,504	+26 —	−31,98	−52,03	+2 —
400	398,1	19,99	1,259	+26 —	−33,98	−58,00	+2 —
500	501,2	15,88	0,631 6	+26 —	−35,98	−63,99	+2 —
630	631,0	12,61	0,316 7	+26 —	−37,98	−69,99	+2 —
800	794,3	10,02	0,158 8	+26 —	−39,98	−75,99	+2 —

1) Preferred frequencies according to ISO 266.

Table 7 — Frequency weighting: whole body, combined, 1 Hz to 80 Hz, based on ISO 2631

Frequency, Hz		Weighting factor (values stated $\times 10^{-3}$)		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
0,1	0,100 0	999,8	15,84	+26 / —	0,00	−36,00	+2 / —
0,125	0,125 9	999,8	25,10	+26 / —	0,00	−32,00	+2 / —
0,16	0,158 5	999,6	39,76	+26 / —	0,00	−28,01	+2 / —
0,2	0,199 5	999,4	62,93	+26 / —	−0,01	−24,02	+2 / —
0,25	0,251 2	999,0	99,41	+26 / —	−0,01	−20,05	+2 / —
0,315	0,316 2	998,5	156,3	+26 / —	−0,01	−16,12	+2 / —
0,4	0,398 1	997,6	243,0	+26 / —	−0,02	−12,29	+2 / —
0,5	0,501 2	996,1	368,4	+26 / −21	−0,03	−8,67	±2
0,63	0,631 0	993,9	530,4	+26 / −21	−0,05	−5,51	±2
0,8	0,794 3	990,4	700,3	+26 / −21	−0,08	−3,09	±2
1	1,000	984,9	832,9	+26 / −21	−0,13	−1,59	±2
1,25	1,259	976,3	907,1	+12 / −11	−0,21	−0,85	±1
1,6	1,585	963,3	934,2	+12 / −11	−0,33	−0,59	±1
2	1,995	943,6	931,9	+12 / −11	−0,50	−0,61	±1
2,5	2,512	914,7	910,1	+12 / −11	−0,77	−0,82	±1
3,15	3,162	873,9	872,1	+12 / −11	−1,17	−1,19	±1
4	3,981	819,1	818,4	+12 / −11	−1,73	−1,74	±1
5	5,012	750,1	749,8	+12 / −11	−2,50	−2,50	±1
6,3	6,310	669,3	669,2	+12 / −11	−3,49	−3,49	±1
8	7,943	581,9	581,9	0	−4,70	−4,70	0
10	10,00	494,2	494,1	+12 / −11	−6,12	−6,12	±1
12,5	12,59	411,5	411,4	+12 / −11	−7,71	−7,71	±1
16	15,85	337,6	337,5	+12 / −11	−9,43	−9,44	±1
20	19,95	274,0	273,8	+12 / −11	−11,25	−11,25	±1
25	25,12	220,7	220,3	+12 / −11	−13,12	−13,14	±1
31,5	31,62	176,9	176,0	+12 / −11	−15,04	−15,09	±1
40	39,81	141,3	139,6	+12 / −11	−16,99	−17,10	±1

Table 7 (*concluded*)

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
50	50,12	112,7	109,3	+12 −11	−18,96	−19,23	±1
63	63,10	89,72	83,36	+12 −11	−20,94	−21,58	±1
80	79,43	71,38	60,36	+26 −21	−22,93	−24,38	±2
100	100,0	56,75	40,13	+26 −21	−24,92	−27,93	±2
125	125,9	45,10	24,07	+26 −21	−26,92	−32,37	±2
160	158,5	35,84	13,26	+26 −21	−28,91	−37,55	±2
200	199,5	28,48	6,937	+26 —	−30,91	−43,18	+2 —
250	251,2	22,62	3,541	+26 —	−32,91	−49,02	+2 —
315	316,2	17,97	1,788	+26 —	−34,91	−54,95	+2 —
400	398,1	14,28	0,899 0	+26 —	−36,91	−60,92	+2 —
500	501,2	11,34	0,451 1	+26 —	−38,91	−66,91	+2 —
630	631,0	9,008	0,226 2	+26 —	−40,91	−72,91	+2 —
800	794,3	7,156	0,413 4	+26 —	−42,91	−78,91	+2 —

1) Preferred frequencies according to ISO 266.

Table 8 — Frequency weighting: hand-arm, based on ISO 5349

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
0,8	0,794 3	1 001	15,86	+26 —	+0,01	−36,00	+2 —
1	1,000	1 001	25,14	+26 —	+0,01	−31,99	+2 —
1,25	1,259	1 002	39,85	+26 —	+0,01	−27,99	+2 —
1,6	1,585	1 003	63,14	+26 —	+0,02	−23,99	+2 —
2	1,995	1 004	99,92	+26 —	+0,04	−20,01	+2 —
2,5	2,512	1 007	157,6	+26 —	+0,06	−16,05	+2 —
3,15	3,162	1 010	246,1	+26 —	+0,09	−12,18	+2 —
4	3,981	1 015	375,4	+26 −21	+0,13	−8,51	±2
5	5,012	1 021	545,0	+26 −21	+0,18	−5,27	±2

Table 8 *(continued)*

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
6,3	6,310	1 028	727,2	+26 −21	+0,24	−2,77	±2
8	7,943	1 032	873,1	+26 −21	+0,28	−1,18	±2
10	10,00	1 024	951,4	+12 −11	+0,21	−0,43	±1
12,5	12,59	987,3	957,6	+12 −11	−0,11	−0,38	±1
16	15,85	907,0	895,8	+12 −11	−0,85	−0,96	±1
20	19,95	785,9	782,0	+12 −11	−2,09	−2,14	±1
25	25,12	648,4	647,1	+12 −11	−3,76	−3,78	±1
31,5	31,62	519,6	519,2	+12 −11	−5,69	−5,69	±1
40	39,81	411,2	411,1	+12 −11	−7,72	−7,72	±1
50	50,12	324,4	324,4	+12 −11	−9,78	−9,78	±1
63	63,10	256,1	256,0	+12 −11	−11,83	−11,83	±1
80	79,43	202,4	202,4	0	−13,88	−13,88	0
100	100,0	160,2	160,2	+12 −11	−15,91	−15,91	±1
125	125,9	127,0	127,0	+12 −11	−17,93	−17,93	±1
160	158,5	100,7	100,7	+12 −11	−19,94	−19,94	±1
200	199,5	79,91	79,88	+12 −11	−21,95	−21,95	±1
250	251,2	63,43	63,38	+12 −11	−23,95	−23,96	±1
315	316,2	50,36	50,26	+12 −11	−25,96	−25,97	±1
400	398,1	40,00	39,80	+12 −11	−27,96	−28,00	±1
500	501,2	31,76	31,37	+12 −11	−29,96	−30,07	±1
630	631,0	25,23	24,47	+12 −11	−31,96	−32,23	±1
800	794,3	20,04	18,62	+12 −11	−33,96	−34,60	±1
1 000	1 000	15,92	13,46	+26 −21	−35,96	−37,42	±2
1 250	1 259	12,64	8,940	+26 −21	−37,96	−40,97	±2
1 600	1 585	10,04	5,359	+26 −21	−39,96	−45,42	±2
2 000	1 995	7,977	2,950	+26 −21	−41,96	−50,60	±2

Table 8 (*concluded*)

Frequency, Hz		Weighting factor (values stated × 10^{-3})		Tolerance %	Weighting gain, dB		Tolerance dB
Nominal	True[1)]	Excluding band-limiting	Including band-limiting		Excluding band-limiting	Including band-limiting	
2 500	2 512	6,336	1,544	+26 —	−43,96	−56,23	+2 —
3 150	3 162	5,033	0,787 8	+26 —	−45,96	−62,07	+2 —
4 000	3 981	3,998	0,397 8	+26 —	−47,96	−68,01	+2 —
5 000	5 012	3,176	0,200 0	+26 —	−49,96	−73,98	+2 —
6 300	6 310	2,522	0,100 3	+26 —	−51,96	−79,97	+2 —
8 000	7 943	2,004	0,050 3	+26 —	−53,96	−85,97	+2 —
10 000	10 000	1,592	0,025 2	+26 —	−55,96	−91,96	+2 —

1) Preferred frequencies according to ISO 266.

6.2 Detector-indicator characteristics

6.2.1 Exponential time weighting

The tests in clause 8 for r.m.s. accuracy and time-weighting characteristics shall be carried out. Allowable errors for various signal crest factors are shown in table 9. The time-weighting characteristics of the detector-indicator shall be such that it will respond to signal bursts as specified in table 10, third column, and to a suddenly applied signal, or step in signal amplitude, without overshoot or with a maximum overshoot of 12 % (1 dB). When the applied signal is suddenly turned off, the indicator without peak detector shall decay by 10 dB in a time of 2,3 s for a 1 s time constant and in a time of 18,4 s for an 8 s time constant.

Table 9 — Maximum error for r.m.s. detector-indicator system

Type of instrumentation	Maximum error for the following values of the crest factor					
	< 3		< 5		< 10	
	%	dB	%	dB	%	dB
1	6	0,5	12	1	19	1,5
2	12	1	12	1	—	—

Table 10 — Response to test signal bursts

Detector-indicator characteristic	Duration of test signal bursts	Maximum response to test signal bursts referred to response to continuous signal		Tolerance on maximum response (referred to the nominal value) for the following types of instrumentation			
				1		2	
	ms	%	dB	%	dB	%	dB
—	Continuous	0	0	—	—	—	—
1 s	500	−37	−4,1	+12 −11	±1	+26 −21	±2
1/8 s	62,5	−37	−4,1	+12 −11	±1	+26 −21	±2
8 s	4 000	−37	−4,1	+12 −11	±1	+26 −21	±2
Peak (< $0{,}2/f_u$)*)	$1/f_u$ kHz (half sine of frequency $0{,}5\,f_u$, either polarity)	41	3**)	+12 −11	±1	+26 −21	±2

*) f_u = upper limiting frequency.

**) Crest factor of a sinusoidal signal.

6.2.2 Linear integration

If the linearly integrated vibration value of a sinusoidal continuous signal is compared with the corresponding value of a sequence of signal bursts the tolerances given in table 11 shall not be exceeded.

Table 11 — Tolerances for linear integration

Pulse duty factor of signal bursts	Relation between the amplitude of the tone bursts and the continuous signal yielding the same integrated value	Tolerances for the following types of instrumentation			
		1		2	
		%	dB	%	dB
10^{-1}	3,16	6	0,5	12	1
10^{-2}	10,0	6	0,5	12	1
10^{-3}	31,6	12	1	25	2

6.3 Peak indicator characteristics

The peak detector shall hold the maximum absolute instantaneous value of the vibration signal. The rise time, if any, shall be small in comparison with one period length of the upper limiting frequency, meaning that the detected peak values of even the shortest pulses possible will have negligible errors. This shall be tested with pulses specified in table 10. The decay time shall be such that any decay within 1 min is less than 6 % (0,5 dB). A reset of the peak hold shall be provided for either manual or automatic operation with a minimum of 300 ms intervals.

NOTE — The user should be aware that the peak value is affected with some uncertainty by the phase characteristic of the instrumentation. The test pulses in table 10 for testing the peak response have been chosen in such a way that the peak value will not be influenced considerably by the phase response.

The peak indicator shall be accurate to within ±6 % (±0,5 dB) for any positive or negative peak within any part of the dynamic range except for a lower limit specified by the manufacturer in the most sensitive range available.

In the peak mode the rise time shall be specified by the manufacturer for the electronic instrumentation part.

6.4 Indicator range

The range of the indicator, whether analogue or digital, shall be at least 1 to 5,6 (15 dB). A range of at least 1 to 3,2 (10 dB) shall be specified as the primary indicator range by the manufacturer.

NOTE — A large indicator range may be required to enable full use of the linear-integration facility.

6.5 Analogue indicator scale

When an analogue indicator is provided, its scale shall be graduated in steps not greater than 12 % (1 dB) over a range of at least 1 to 5,6 (15 dB). Each step shall be at least 1 mm wide. The calibration procedure to ensure the quoted overall accuracy at a reference frequency shall be stated by the manufacturer.

If a quasi-analogue indicator (continuous display, for example light-emitting diode and liquid-crystal display devices with level steps) is provided, it shall have a resolution of at least 1 dB for type 1 and 2 dB for type 2 instrumentation. For calibration purposes a method shall be given to ensure a repeatability of 0,1 dB for type 1 and at least 0,5 dB for type 2 instrumentation.

6.6 Digital indicator display

A digital indicator shall display at least the instantaneous values in the time-weighting mode. Additionally, it may display maximum values. The resolution shall be 0,1 dB for type 1 and 0,5 dB or better for type 2 instrumentation.

6.7 Linearity

The linearity of the system consisting of the detector-indicator and any manual or automatic range controls shall be tested and shall satisfy the requirements of table 12. The reference magnitude for testing linearity is the reference vibration.

Table 12 — Tolerances on sensitivity linearity referred to the reference vibration and reference frequency

Readings	Type 1 instrumentation		Type 2 instrumentation	
	%	dB	%	dB
Inside primary indicator range	±8	±0,7	+12 −11	±1
Outside primary indicator range	+12 −11	±1	+19 −16	±1,5

7 Sensitivity to various environments

Vibration-measuring instrumentation shall meet the requirements in 7.1 to 7.4, depending on the particular application.

7.1 Mechanical vibration

The performance of the instrumentation, excluding the vibration transducer, shall be within the specified tolerances in the following environments.

For a given sinusoidal vibration environment, specified as having a frequency range of 5 Hz to 13,4 Hz and a constant displacement amplitude of 1 mm or a frequency range of 13,4 Hz to 150 Hz and a constant acceleration amplitude of 7 m/s^2, the instrumentation shall be subjected to a performance test and to an endurance test. For both tests the transducer is replaced by an equivalent electrical impedance combined with an input signal corresponding to a half-scale indication in an arbitrary setting of the range and mode controls.

The instrumentation shall be attached properly to the shaker table and the tests shall be carried out in three mutually perpendicular directions.

During the performance test the instrumentation shall be switched on, and during one sweep from 5 Hz to 150 Hz to 5 Hz, with a sweep rate of 1 octave/min, the output indication shall be stable within the tolerances of the instrumentation.

For the endurance test the instrumentation is switched off and shall withstand a sine sweep test of 2 h in each of the three directions. The instrumentation passes the test if no deterioration or any mechanical damage can be established. For instrumentation that will not be used in the field, less severe vibration test specifications can be accepted. The manufacturer shall provide the test specification used, including the test conditions and the acceptance criteria used.

7.2 Magnetic and electrostatic fields

The effects of magnetic and electrostatic fields shall be reduced as far as practicable. Vibration-measuring instrumentation with an attached transducer shall be tested in a magnetic field of strength 80 A/m[1)] at 50 Hz or 60 Hz. The apparatus shall be oriented in a direction which gives maximum indication, and this indication shall be stated for each of the weighting characteristics provided.

7.3 Temperature range

The temperature range over which the calibration of the complete instrument, including the transducer, is not affected by more than ±6 % (±0,5 dB) for type 1 and type 2 instrumentation referred to the indication at the reference temperature of 20 °C shall be specified by the manufacturer. If the change in calibration of the instrumentation intended for field use exceeds ±6 % (±0,5 dB) in the temperature range −10 °C to +50 °C, correction information shall be provided by the manufacturer. The test shall be performed at the reference frequency.

NOTE — The relative humidity at which the test is carried out should be specified (see 7.4).

7.4 Humidity range

The manufacturer shall state the humidity range over which the complete instrumentation, including the transducer, is intended to operate continuously. If the instrumentation is intended for field use then, with a reference frequency applied to the input, the relative humidity should be varied between 30 % and 90 %. If 65 % r.h. is used as the reference point, the indication should not vary by more than ±6 % (±0,5 dB) over the humidity range specified.

1) 80 A/m = 1 Oe (œrsted)

8 Calibration and verification of the basic characteristics of the vibration-measuring instrumentation

8.1 General

The tests described in 8.5 and 8.6 shall be used to check that the requirements of 5.5, 5.6 and 6.2.1 are met.

8.2 Reference conditions

Reference conditions shall be as given in 3.8 and 3.9.

8.3 Compliance with requirements

Although the frequency-weighting characteristics and detector-indicator characteristics are usually associated with particular circuits within the vibration-measuring instrumentation, the tests to determine compliance with the requirements of clause 6 shall be valid for the complete instrument. In this way, any interaction between the various elements of the instrumentation will be taken into account.

8.4 Test without transducer

The manufacturer shall specify the means to substitute an electrical signal for the transducer for the purpose of performing tests on the complete instrument without the transducer.

The tests in clause 6 and in 8.5 and 8.6 may be carried out without the transducer.

8.5 Tests of the overload and detection characteristics

Tests of the overload and detection characteristics of the instrument for compliance with clause 6 are carried out with rectangular-pulse sequences and with signal bursts as described in 8.5.1 and 8.5.2 respectively.

8.5.1 Rectangular-pulse rate (see figure 1)

Apply the sinusoidal signal to the instrumentation under test and simultaneously to a reference system having a true r.m.s. response and a frequency-weighting network N corresponding to that in the vibration-measuring instrumentation being tested within the tolerances given in tables 4 to 8. Note the indication of the reference meter.

Apply the rectangular-pulse sequence and adjust its amplitude to produce an indication on the reference r.m.s. meter identical to that for the sinusoidal signal. The instrumentation under test shall then give an indication within the tolerance specified in table 9. This test shall be carried out so that correct performance of the instrument is ensured in the whole primary indicator range.

For the rectangular pulse shown, the relation between the crest factor $\hat{u}/u$ and the pulse duty factor $t_{\hat{u}}/T$ is given by

$$\hat{u}/u = \sqrt{T/t_{\hat{u}} - 1}$$

where

$\hat{u}$ is the peak value of the signal, the instantaneous value being measured with reference to the arithmetic mean;

u is the r.m.s. value of the signal, the instantaneous value being measured with reference to the arithmetic mean;

T is the fundamental period of the signal;

$t_{\hat{u}}$ is the time during which the signal is at its peak value $\hat{u}$.

8.5.2 Signal-burst test

The rectangular-pulse generator in 8.5.1 is replaced by a signal-burst generator and the procedure described is repeated using the appropriate crest factor. The relation between the crest factor and the pulse duty factor for this case is given by

$$\hat{u}/u = \sqrt{2T/t_i}$$

where

$\hat{u}$, u and T are as defined in 8.5.1;

t_i is the time during which the signal has a non-zero value.

8.6 Verification of the signal-to-noise ratio

When the transducer is replaced by an equivalent electrical impedance, the reading shall be at least a factor of 0,6 (5 dB) below the specified minimum weighted vibration measurable for each of the weighting curves.

9 Rating information and instruction manual

9.1 Marking of an instrument

A vibration-measuring instrument that complies with this International Standard shall be marked to show its type (see clause 1). It shall also be marked with the name of the manufacturer, the model number and the serial number.

9.2 Instruction manual

An instruction manual shall be supplied with the vibration-measuring instrument; it shall include at least the information listed below.

1) The kind of transducer and method of mounting in order to attain the tolerances required for that particular type of instrument.

2) The range of weighted vibration magnitudes which the instrument is designed to measure within the tolerances of this International Standard. The limits shall be stated separately for each frequency-weighting characteristic, as necessary.

3) The reference acceleration used, if different from 10^{-6} m/s^2.

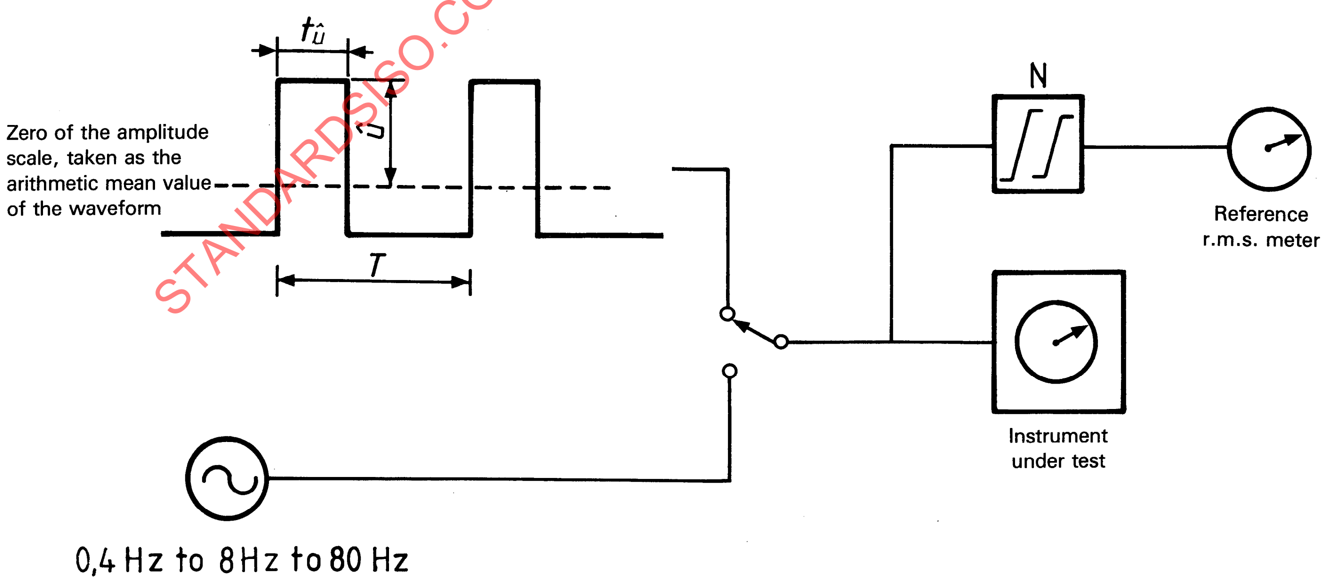

Figure 1 — Rectangular-pulse test

4) The reference calibration frequency as defined in 3.8.

5) The reference calibration vibration as defined in 3.9.

6) Frequency range and tolerances for flat response, if provided.

7) Information on whether the averaging process is dependent on the time constant (see 4.3.2).

8) The warm-up time before valid readings can be made, as defined in 4.6.

9) The settling time for the automatic range-control system, if provided (see 5.4).

10) The possibility of erroneous readings due to overloading, if appropriate.

11) The upper limit of measurable vibration.

12) At the upper limit of each primary indicator range, the frequency for which the error resulting from non-linear distortion generated between the vibratory input and the signal output is less than $^{+12\%}_{-11\%}$ (± 1 dB).

13) A description of the detector-indicator characteristics (1/8 s, 1 s, 8 s, L_{weq} and peak, as applicable) specified in clause 6.

14) The effect of vibration on the operation of the vibration-measuring instrumentation as tested in accordance with 7.1 and a statement as to whether the instrumentation meets the requirements for field use according to 7.1.

15) The effect of magnetic fields as tested in accordance with 7.2.

16) The effects of temperature as tested in accordance with 7.3 and, if necessary, the corrections for field use required in 7.3.

17) The effects of humidity as tested in accordance with 7.4.

18) The limits of temperature and humidity beyond which permanent damage to the vibration-measuring instrumentation may result.

19) Any correction to calibration required when a transducer extension cable is used.

20) The effect on the performance of the instrument caused by the use of recommended transducer accessories such as magnetic mountings.

21) The calibration procedure necessary to maintain the accuracy as specified in 4.4.

22) A procedure to ensure optimum operating conditions when the vibration-measuring instrumentation is used with external filters or analysers, if applicable.

23) The limitations on the electrical impedance that may be connected to the output connector, if one is provided.

24) For the type 1 instrumentation, typical continuous frequency response curves.

25) The electrical impedance which shall be substituted for the transducer testing purposes.

26) The primary indicator range, as specified in 6.4.

27) The requirements for power supply and acceptable limits.

28) The transducer specifications in accordance with ISO 8042.

Annex A
(informative)

Additional information

A.1 Method of use

It is recognized that vibration-measuring instrumentation may be used to measure many types of vibration under different conditions and for a variety of reasons. For each application, the measurement technique should be chosen and carefully controlled to obtain valid and consistent results. It is important to note that the method of use has at least as much effect on a measurement as the quality of the instrumentation itself; errors will often result if the effect of the environment and correct application of the transducer are ignored.

A.2 Weightings

Frequency and time weightings are important for the magnitude of measured vibration. The knowledge about subjective characteristics of human sensation is limited. It is, however, important for the consistency of reported results to use well defined characteristics. Standardization of the time-weighting characteristics does not imply that the relationship between subjective perceived impulsive vibration magnitudes and the physical characteristics of vibration is thereby precisely represented.

A.3 Time constants

For proper choice of time constants, consult the appropriate International Standard (see clause 2). See also annex D.

A.4 Short-duration signals

A wide dynamic range, an overload indication and a high crest factor capability are necessary for the accurate measurement of short-duration vibratory motion; these characteristics are specified in this International Standard.

A.5 Multi-axis measurements

In vibration measurements it is often desirable to measure more than one axis. For continuous or very repetitive signals, consecutive measurements of the x, y and z axis may be carried out and the maximum r.m.s. weighted acceleration a_w obtained from the following formula:

$$a_w = \sqrt{a_{xw}^2 + a_{yw}^2 + a_{zw}^2}$$

NOTE — To use this formula for the measurement of whole-body vibration according to ISO 2631-1, factors should be applied to a_{xw} and a_{yw} as given in ISO 2631-1.

Use of this calculation will result in an evaluation giving the maximum value which may occur. The minimum value will be represented by the largest single axis value. The use of 60 s linear integrated r.m.s. detection is recommended.

Alternatively, the maximum r.m.s. value obtained in a specified time interval using exponential time averaging may be used. The time constant should be reported as this will seriously affect the measured results when measuring signals with large crest factors.

Annex B
(informative)

Analytical expressions corresponding to tables 4 to 8

B.1 Nomenclature

f_l	Lower limiting frequency, in hertz
f_u	Upper limiting frequency, in hertz
H (with subscript)	Complex transfer functions describing the frequency weighting and frequency bandlimiting; $\lvert H \rvert$ is the magnitude of H
N_l, N_u	Integer numbers determining f_l and f_u
p	Imaginary angular frequency $j2\pi f$ in the frequency domain, in reciprocal seconds

B.2 Weighting functions

The analytical expressions of the weighting functions from which tables 4 to 8 were derived are presented below.

The first expressions (all numerals except 1 and 0,42 in units of milliseconds) define exactly the magnitude of the functions and the second expressions (all numerals except 1 and 0,18 in units of hertz) are slightly rounded. The phase shift is implicitly given by the first expressions.

Frequency-weighting function: whole body, 1 Hz to 80 Hz ($N_l = 0$, $N_u = 19$):

$$|H_x| = |H_y| = \left| \frac{1 + p \times 80}{1 + p \times 125 + (p \times 80)^2} \right| \approx \sqrt{\frac{1 + (f/2)^2}{[1 - (f/2)^2]^2 + (f/1{,}28)^2}}$$

$$|H_z| = \left| \frac{0{,}42 + p \times 45}{1 + p \times 44 + (p \times 30)^2} \right| \approx \sqrt{\frac{0{,}18 + (f/3{,}54)^2}{[1 - f^2/(8 \times 3{,}54)]^2 + (f/3{,}62)^2}}$$

$$|H_{combined}| = \left| \frac{1}{1 + p \times 28} \right| \approx \frac{1}{\sqrt{1 + (f/5{,}7)^2}}$$

Frequency-weighting function: motion sickness, 0,1 Hz to 0,63 Hz ($N_l = -10$, $N_u = -2$):

$$|H_{ms}| = \left| \frac{1 + p \times 105}{1 + p \times 581 + (p \times 472)^2} \right| \approx \sqrt{\frac{1 + (f/1{,}516)^2}{[1 - (f/0{,}337)^2]^2 + (f/0{,}274)^2}}$$

Frequency-weighting function: hand-arm, 8 Hz to 1 000 Hz ($N_l = 9$, $N_u = 30$):

$$|H_{H.-A.}| = \left| \frac{1 + p \times 10}{1 + p \times (10^3/64) + (p \times 10)^2} \right| \approx \sqrt{\frac{1 + (f/16)^2}{[1 - (f/16)^2]^2 + (f/10{,}2)^2}}$$

Bandlimiting filter function (combined high pass and low pass; 2 pole Butterworth):

$$|H_{bl}| = \left| \left[1 + \sqrt{2}\frac{2\pi f_l \times 10^{-0{,}1}}{p} + \left(\frac{2\pi f_l \times 10^{-0{,}1}}{p}\right)^2\right]^{-1} \left[1 + \sqrt{2}\frac{p}{2\pi f_u \times 10^{0{,}1}} + \left(\frac{p}{2\pi f_u \times 10^{0{,}1}}\right)^2\right]^{-1} \right|$$

$$= \left[1 + \left(\frac{f_l \times 10^{-0{,}1}}{f}\right)^4\right]^{-0{,}5} \left[1 + \left(\frac{f \times 10^{-0{,}1}}{f_u}\right)^4\right]^{-0{,}5}$$

The lower and upper limiting frequencies f_l and f_u shall be the corrected values of the preferred frequencies according to ISO 266: $f_l = 10^{0{,}1 N_l}$; $f_u = 10^{0{,}1 N_u}$.