INTERNATIONAL STANDARD

ISO 2631-1

Second edition
1997-05-01

Corrected and reprinted
1997-07-15

Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration —

Part 1:
General requirements

Vibrations et chocs mécaniques — Évaluation de l'exposition des individus à des vibrations globales du corps —

Partie 1: Exigences générales

Reference number
ISO 2631-1:1997(E)

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X.400 c=ch; a=400net; p=iso; o=isocs; s=central

Printed in Switzerland

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 voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 2631-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock.*

This second edition cancels and replaces the first edition (ISO 2631-1:1985) and ISO 2631-3:1985.

ISO 2631 consists of the following parts, under the general title *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration*:

— *Part 1: General requirements*

— *Part 2: Continuous and shock-induced vibration in buildings* (1 to 80 Hz)

Annex A forms an integral part of this part of ISO 2631. Annexes B to E are for information only.

The revision of this part of ISO 2631 incorporates new experience and research results reported in the literature which made it desirable to

— reorganize the parts of this International Standard;

— change the method of measurement and analysis of the vibration environment;

— change the approach to the application of the results.

Increasing awareness of the complexity of human physiological/pathological response as well as behavioral response to vibration and the lack of clear, universally recognized dose-response relationships made it desirable to give more quantitative guidance on the effects of vibration on health and comfort as well as on perception and the incidence of motion sickness (see annexes B to D).

The frequency range in this revision is extended below 1 Hz and the evaluation is based on frequency weighting of the r.m.s. acceleration rather than the rating method. Different frequency weightings are given for the evaluation of different effects.

Based on practical experience, r.m.s. methods continue to be the basis for measurements for crest factors less than 9 and consequently the integrity of existing databases is maintained. Studies in recent years have pointed to the importance of the peak values of acceleration in the vibration exposure, particularly in health effects. The r.m.s. method of assessing vibration has been shown by several laboratories to underestimate the effects for vibration with substantial peaks. Additional and/or alternative measurement procedures are presented for vibration with such high peaks and particularly for crest factors greater than 9, while the r.m.s. method is extended to crest factors less than or equal to 9.

For simplicity, the dependency on exposure duration of the various effects on people had been assumed in ISO 2631-1:1985 to be the same for the different effects (health, working proficiency and comfort). This concept was not supported by research results in the laboratory and consequently has been removed. New approaches are outlined in the annexes. Exposure boundaries or limits are not included and the concept of "fatigue-decreased proficiency" due to vibration exposure has been deleted.

In spite of these substantial changes, improvements and refinements in this part of ISO 2631, the majority of reports or research studies indicate that the guidance and exposure boundaries recommended in ISO 2631-1:1985 were safe and preventive of undesired effects. This revision of ISO 2631 should not affect the integrity and continuity of existing databases and should support the collection of better data as the basis for the various dose-effect relationships.

Introduction

The primary purpose of this part of ISO 2631 is to define methods of quantifying whole-body vibration in relation to

- human health and comfort;
- the probability of vibration perception;
- the incidence of motion sickness.

This part of ISO 2631 is concerned with whole-body vibration and excludes hazardous effects of vibration transmitted directly to the limbs (e.g. by power tools).

Vehicles (air, land and water), machinery (for example, those used in industry and agriculture) and industrial activities (such as piling and blasting), expose people to periodic, random and transient mechanical vibration which can interfere with comfort, activities and health.

This part of ISO 2631 does not contain vibration exposure limits. However, evaluation methods have been defined so that they may be used as the basis for limits which may be prepared separately. It contains methods for the evaluation of vibration containing occasional high peak values (having high crest factors).

Three annexes provide current information on the possible effects of vibration on health (annex B), comfort and perception (annex C) and on the incidence of motion sickness (annex D). This guidance is intended to take into account all the available data and to satisfy the need for recommendations which are simple and suitable for general application. The guidance is given in numerical terms to avoid ambiguity and to encourage precise measurements. However, when using these recommendations it is important to bear in mind the restrictions placed on their application. More information may be obtained from the scientific literature, a part of which is listed in annex E.

This part of ISO 2631 does not cover the potential effects of intense vibration on human performance and task capability since such guidance depends critically on ergonomic details related to the operator, the situation and the task design.

Vibration is often complex, contains many frequencies, occurs in several directions and changes over time. The effects of vibration may be manifold. Exposure to whole-body vibration causes a complex distribution of oscillatory motions and forces within the body. There can be large variations between subjects with respect to biological effects. Whole-body vibration may cause sensations (e.g. discomfort or annoyance), influence human performance capability or present a health and safety risk (e.g. pathological damage or physiological change). The presence of oscillatory force with little motion may cause similar effects.

Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration —

Part 1:
General requirements

1 Scope

This part of ISO 2631 defines methods for the measurement of periodic, random and transient whole-body vibration. It indicates the principal factors that combine to determine the degree to which a vibration exposure will be acceptable. Informative annexes indicate current opinion and provide guidance on the possible effects of vibration on health, comfort and perception and motion sickness. The frequency range considered is

— 0,5 Hz to 80 Hz for health, comfort and perception, and

— 0,1 Hz to 0,5 Hz for motion sickness.

Although the potential effects on human performance are not covered, most of the guidance on whole-body vibration measurement also applies to this area. This part of ISO 2631 also defines the principles of preferred methods of mounting transducers for determining human exposure. It does not apply to the evaluation of extreme-magnitude single shocks such as occur in vehicle accidents.

This part of ISO 2631 is applicable to motions transmitted to the human body as a whole through the supporting surfaces: the feet of a standing person, the buttocks, back and feet of a seated person or the supporting area of a recumbent person. This type of vibration is found in vehicles, in machinery, in buildings and in the vicinity of working machinery.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 2631. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 2631 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 2041:1990, *Vibration and shock — Vocabulary.*

ISO 5805:1997, *Mechanical vibration and shock — Human exposure — Vocabulary.*

ISO 8041:1990, *Human response to vibration — Measuring instrumentation.*

IEC 1260:1995, *Electroacoustics — Octave-band and fractional-octave-band filters.*

3 Definitions

For the purposes of this part of ISO 2631, the terms and definitions given in ISO 2041 and ISO 5805 apply.

4 Symbols and subscripts

4.1 Symbols

a	Vibration acceleration. Translational acceleration is expressed in metres per second squared (m/s^2) and rotational acceleration is expressed in radians per second squared (rad/s^2). Values are quoted as root-mean-square (r.m.s) unless stated otherwise
$H(p)$	Transfer function, or gain, of a filter expressed as a function of the imaginary angular frequency (complex frequency)
$p = \mathrm{j}\, 2\, \pi f$	Imaginary angular frequency
W	Frequency weighting

4.2 Subscripts

c, d, e, f, j, k	Refer to the various frequency-weighting curves recommended for evaluation with respect to health, comfort, perception and motion sickness (see tables 1 and 2).
w	Refers to frequency-weighted acceleration values.
x, y, z	Refer to the direction of translational, or rectilinear, vibration (see figure 1). For rotational vibration, they refer to the axis of rotation, r. (Rotation about x-, y- and z-axes is designated roll, pitch and yaw, respectively, see figure 1.)
v	Refers to the vector sum of the overall weighted acceleration in the x-, y- and z-axes.

Table 1 — Guide for the application of frequency-weighting curves for principal weightings

Frequency weighting	Health (see clause 7)	Comfort (see clause 8)	Perception (see clause 8)	Motion sickness (see clause 9)
W_k	z-axis, seat surface	z-axis, seat surface z-axis, standing vertical recumbent (except head) x-, y-, z-axes, feet (sitting)	z-axis, seat surface z-axis, standing vertical recumbent (except head)	—
W_d	x-axis, seat surface y-axis, seat surface	x-axis, seat surface y-axis, seat surface x-, y-axes, standing horizontal recumbent y-, z-axes, seat-back	x-axis, seat surface y-axis, seat surface x-, y-axes, standing horizontal recumbent	—
W_f	—	—	—	vertical

Table 2 — Guide for the application of frequency-weighting curves for additional weighting factors

Frequency weighting	Health (see clause 7)	Comfort (see clause 8)	Perception (see clause 8)	Motion sickness (see clause 9)
W_c	x-axis, seat-back 1)	x-axis, seat-back	x-axis, seat-back	—
W_e	—	r_x-, r_y-, r_z-axes, seat surface	r_x-, r_y-, r_z-axes, seat surface	—
W_j	—	vertical recumbent (head) 2)	vertical recumbent (head) 2)	—

1) See note in subclause 7.2.3.
2) See note in subclause 8.2.2.3.

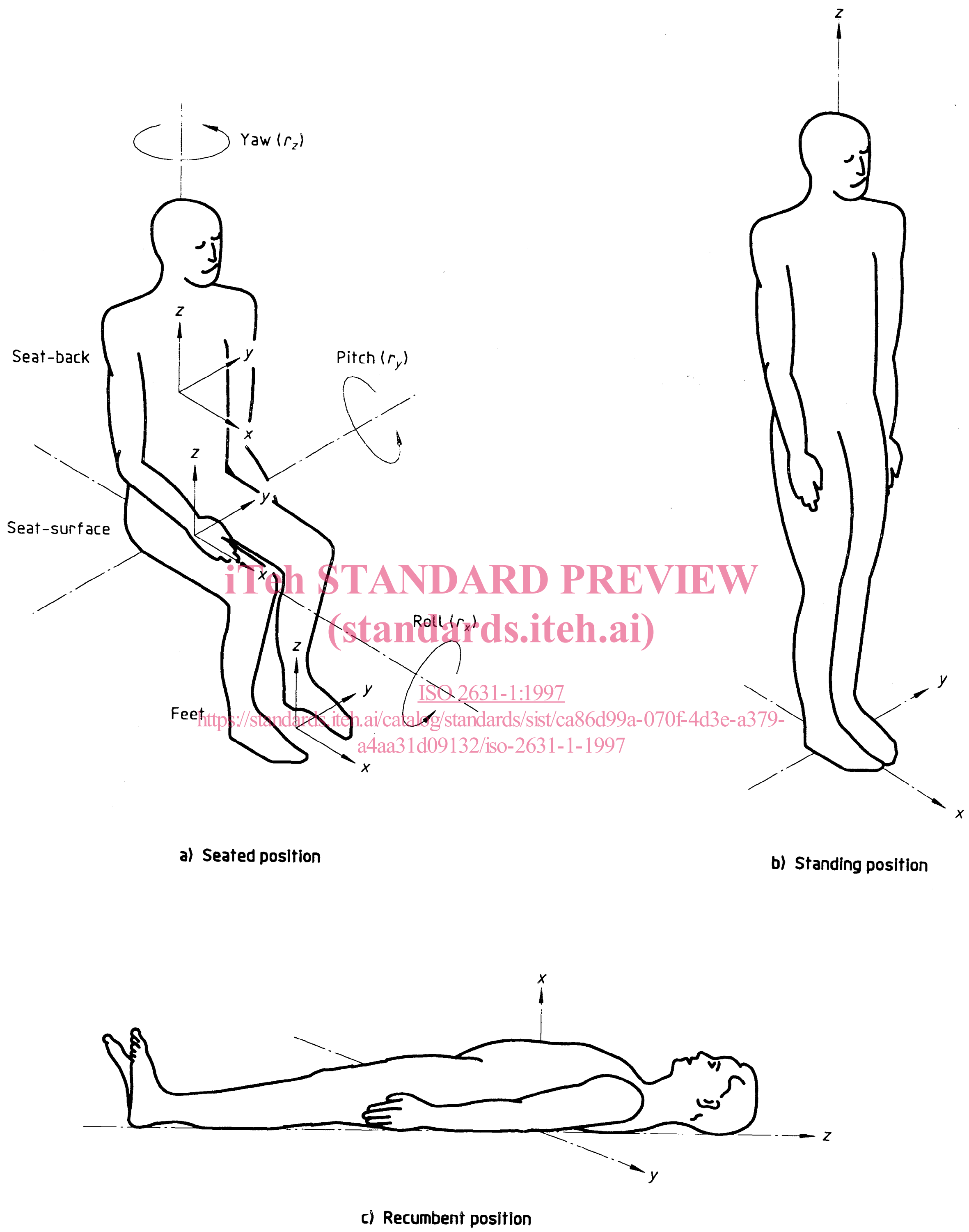

Figure 1 — Basicentric axes of the human body

5 Vibration measurement

5.1 General

The primary quantity of vibration magnitude shall be acceleration (see 4.1).

In case of very low frequencies and low vibration magnitudes, e.g. in buildings or ships, velocity measurements may be made and translated into accelerations.

5.2 Direction of measurement

5.2.1 Vibration shall be measured according to a coordinate system originating at a point from which vibration is considered to enter the human body. The principal relevant basicentric coordinate systems are shown in figure 1.

5.2.2 If it is not feasible to obtain precise alignment of the vibration transducers with the preferred basicentric axes, the sensitive axes of transducers may deviate from the preferred axes by up to 15° where necessary. For a person seated on an inclined seat, the relevant orientation should be determined by the axes of the body, and the z-axis will not necessarily be vertical. The orientation of the basicentric axes to the gravitational field should be noted.

5.2.3 Transducers located at one measurement location shall be positioned orthogonally. Translational accelerometers orientated in different axes at a single measurement location shall be as close together as possible.

5.3 Location of measurement

5.3.1 Transducers shall be located so as to indicate the vibration at the interface between the human body and the source of its vibration.

Vibration which is transmitted to the body shall be measured on the surface between the body and that surface.

The principal areas of contact between the body and a vibrating surface may not always be self-evident. This part of ISO 2631 uses three principal areas for seated persons: the supporting seat surface, the seat-back and the feet. Measurements on the supporting seat surface should be made beneath the ischial tuberosities. Measurements on the seat-back should be made in the area of principal support of the body. Measurements at the feet should be made on the surface on which the feet are most often supported. For recumbent positions, this part of ISO 2631 considers the supporting surface to be under the pelvis, the back and the head. In all cases the location of measurement shall be fully reported.

NOTES

1 Where direct measurements are not practicable, vibration may be measured at a rigid portion of the vehicle or building structure such as the centre of rotation or the centre of gravity. The evaluation of such data in terms of human response requires additional calculations and requires knowledge about the structural dynamics of the system being evaluated.

2 Measurements at the seat-back are preferably made at the interface with the body. Where this is difficult, measurements may be made on the frame of the seat behind the backrest cushion. If measurements are made at this position they are to be corrected for the transmissibility of the cushion material.

3 Vibration which is transmitted to the body from rigid surfaces may be measured on the supporting surface closely adjacent to the area of contact between the body and that surface (usually within 10 cm of the centre of this area).

5.3.2 Vibration which is transmitted to the body from a non-rigid or resilient material (e.g. the seat cushion or couch) shall be measured with the transducer interposed between the person and the principal contact areas of the surface. This should be achieved by securing the transducers within a suitably formed mount. The mount shall not greatly alter the pressure distribution on the surface of the resilient material. For measurements on non-rigid surfaces, a person shall adopt the normal position for the environment.

NOTE — A commonly used design for accelerometer mount for seat vibration measurements is given in ISO 10326-1.

5.4 General requirements for signal conditioning

The vibration evaluation procedures defined in this part of ISO 2631 incorporate methods of averaging vibration over time and over frequency bands. The frequency response of the vibration transducer and associated signal conditioning prior to signal processing shall be appropriate to the range of frequencies specified in the relevant clauses of this part of ISO 2631.

The dynamic range of the signal-conditioning equipment shall be adequate for the highest and lowest signals. Signals to be recorded for later analysis may first be passed through a low-pass filter having a cutoff (– 3 dB) frequency of approximately 1,5 times the highest frequency of interest in order to maximize the signal-to-noise ratio and the phase characteristic shall be linear within the range of frequencies specified in the relevant clauses of this part of ISO 2631.

5.5 Duration of measurement

The duration of measurement shall be sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are being assessed. The duration of measurement shall be reported.

Where complete exposure consists of various periods of different characteristics, separate analysis of the various periods may be required.

NOTE — For stationary random signals, the measurement accuracy depends on the filter bandwidth and measurement duration. For example, to obtain a measurement error of less than 3 dB at a confidence level of 90 % requires a minimum measurement duration of 108 s for a lower limiting frequency (LLF) of 1 Hz and 227 s for a LLF of 0,5 Hz, when the analysis is done with a one-third octave bandwidth. The measurement period is normally much longer, such that it is representative of the vibration exposure.

5.6 Reporting of vibration conditions

This part of ISO 2631 has been formulated to simplify and standardize the reporting, comparison and assessment of vibration conditions. Proper use of this standard should result in clear documentation of results. This will involve a reference to the appropriate clauses and annexes of this part of ISO 2631 and to one or more of the frequency weightings.

Where alternative methods are described in this part of ISO 2631 it is important that the methods used are clearly reported.

Users of this part of ISO 2631 are encouraged to report both the magnitude and duration of any vibration exposure being assessed. If additional evaluation methods are applied according to 6.3 (e.g. when the crest factor is greater than 9) both the basic value and the additional value shall be reported. If the crest factor is determined, the time period of its measurement should be reported.

The specification of the severity of complex vibration conditions by one, or a few, values is convenient and often essential. However, it is desirable that more detailed information on vibration conditions become available. Reports should include information on the frequency content (i.e. vibration spectra), vibration axes, how conditions change over time, and any other factors which may influence the effect.

NOTE — Other factors may also affect human response to vibration: population type (age, gender, size, fitness, etc.); experience, expectation, arousal and motivation (e.g. difficulty of task to be performed); body posture; activities (e.g. driver or passenger); financial involvement.

6 Vibration evaluation

6.1 Basic evaluation method using weighted root-mean-square acceleration

The vibration evaluation according to this part of ISO 2631 shall always include measurements of the weighted root-mean-square (r.m.s.) acceleration, as defined in this subclause.

The weighted r.m.s. acceleration is expressed in metres per second squared (m/s2) for translational vibration and radians per second squared (rad/s2) for rotational vibration. The weighted r.m.s. acceleration shall be calculated in accordance with the following equation or its equivalents in the frequency domain

$$a_{\mathrm{w}} = \left[\frac{1}{T} \int_{0}^{T} a_{\mathrm{w}}^{2}(t)\, \mathrm{d}t \right]^{\frac{1}{2}} \qquad \ldots (1)$$

where

$a_{\mathrm{w}}(t)$ is the weighted acceleration (translational or rotational) as a function of time (time history), in metres per second squared (m/s2) or radians per second squared (rad/s2), respectively;

T is the duration of the measurement, in seconds.

Frequency-weighting curves recommended and/or used for the various directions and their applications are listed in tables 1 and 2 and discussed in the following subclauses and in annexes B, C and D. Numerical values of the weighting curves are given in tables 3 and 4 and exact definitions are given in annex A.

6.2 Applicability of the basic evaluation method

6.2.1 Definition of crest factor

For the purposes of this part of ISO 2631 the crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration signal to its r.m.s. value. The peak value shall be determined over the duration of measurement (see 5.5), i.e. the time period T used for the integration of the r.m.s. value (see 6.1).

NOTE — The crest factor does not necessarily indicate the severity of vibration (see 6.3).

6.2.2 Applicability of the basic evaluation method for vibration with high crest factors

The crest factor may be used to investigate if the basic evaluation method is suitable for describing the severity of the vibration in relation to its effects on human beings. For vibration with crest factors below or equal to 9, the basic evaluation method is normally sufficient. Subclause 6.3 defines methods applicable when the basic evaluation method is not sufficient.

NOTE — For certain types of vibrations, especially those containing occasional shocks, the basic evaluation method may underestimate the severity with respect to discomfort even when the crest factor is not greater than 9. In cases of doubt it is therefore recommended to use and report additional evaluations also for crest factors less than or equal to 9 according to 6.3. Subclause 6.3.3 indicates ratios between magnitudes evaluated by the additional methods and the basic method, above which it is recommended to use one of the additional methods, as a further basis for judgement of the influence on human beings.

6.3 Additional evaluation of vibration when the basic evaluation method is not sufficient

In cases where the basic evaluation method may underestimate the effects of vibration (high crest factors, occasional shocks, transient vibration), one of the alternative measures described below should also be determined — the running r.m.s. or the fourth power vibration dose value.

Table 3 — Principal frequency weightings in one-third octaves

Frequency band number[1)] x	Frequency f Hz	W_k factor × 1 000	W_k dB	W_d factor × 1 000	W_d dB	W_f factor × 1 000	W_f dB
− 17	0,02					24,2	− 32,33
− 16	0,025					37,7	− 28,48
− 15	0,031 5					59,7	− 24,47
− 14	0,04					97,1	− 20,25
− 13	0,05					157	− 16,10
− 12	0,063					267	− 11,49
− 11	0,08					461	− 6,73
− 10	0,1	31,2	− 30,11	62,4	− 24,09	695	− 3,16
− 9	0,125	48,6	− 26,26	97,3	− 20,24	895	− 0,96
− 8	0,16	79,0	− 22,05	158	− 16,01	1 006	0,05
− 7	0,2	121	− 18,33	243	− 12,28	992	− 0,07
− 6	0,25	182	− 14,81	365	− 8,75	854	− 1,37
− 5	0,315	263	− 11,60	530	− 5,52	619	− 4,17
− 4	0,4	352	− 9,07	713	− 2,94	384	− 8,31
− 3	0,5	418	− 7,57	853	− 1,38	224	− 13,00
− 2	0,63	459	− 6,77	944	− 0,50	116	− 18,69
− 1	0,8	477	− 6,43	992	− 0,07	53,0	− 25,51
0	1	482	− 6,33	1 011	0,10	23,5	− 32,57
1	1,25	484	− 6,29	1 008	0,07	9,98	− 40,02
2	1,6	494	− 6,12	968	− 0,28	3,77	− 48,47
3	2	531	− 5,49	890	− 1,01	1,55	− 56,19
4	2,5	631	− 4,01	776	− 2,20	0,64	− 63,93
5	3,15	804	− 1,90	642	− 3,85	0,25	− 71,96
6	4	967	− 0,29	512	− 5,82	0,097	− 80,26
7	5	1 039	0,33	409	− 7,76		
8	6,3	1 054	0,46	323	− 9,81		
9	8	1 036	0,31	253	− 11,93		
10	10	988	− 0,10	212	− 13,91		
11	12,5	902	− 0,89	161	− 15,87		
12	16	768	− 2,28	125	− 18,03		
13	20	636	− 3,93	100	− 19,99		
14	25	513	− 5,80	80,0	− 21,94		
15	31,5	405	− 7,86	63,2	− 23,98		
16	40	314	− 10,05	49,4	− 26,13		
17	50	246	− 12,19	38,8	− 28,22		
18	63	186	− 14,61	29,5	− 30,60		
19	80	132	− 17,56	21,1	− 33,53		
20	100	88,7	− 21,04	14,1	− 36,99		
21	125	54,0	− 25,35	8,63	− 41,28		
22	160	28,5	− 30,91	4,55	− 46,84		
23	200	15,2	− 36,38	2,43	− 52,30		
24	250	7,90	− 42,04	1,26	− 57,97		
25	315	3,98	− 48,00	0,64	− 63,92		
26	400	1,95	− 54,20	0,31	−70,12		

1) Index x is the frequency band number according to IEC 1260.

NOTES

1 For tolerances of the frequency weightings, see 6.4.1.2.

2 If it has been established that the frequency range below 1 Hz is unimportant to the weighted acceleration value, a frequency range 1 Hz to 80 Hz is recommended.

3 The values have been calculated including frequency band limitation.