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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
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International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet central@iso.ch
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Annexes

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

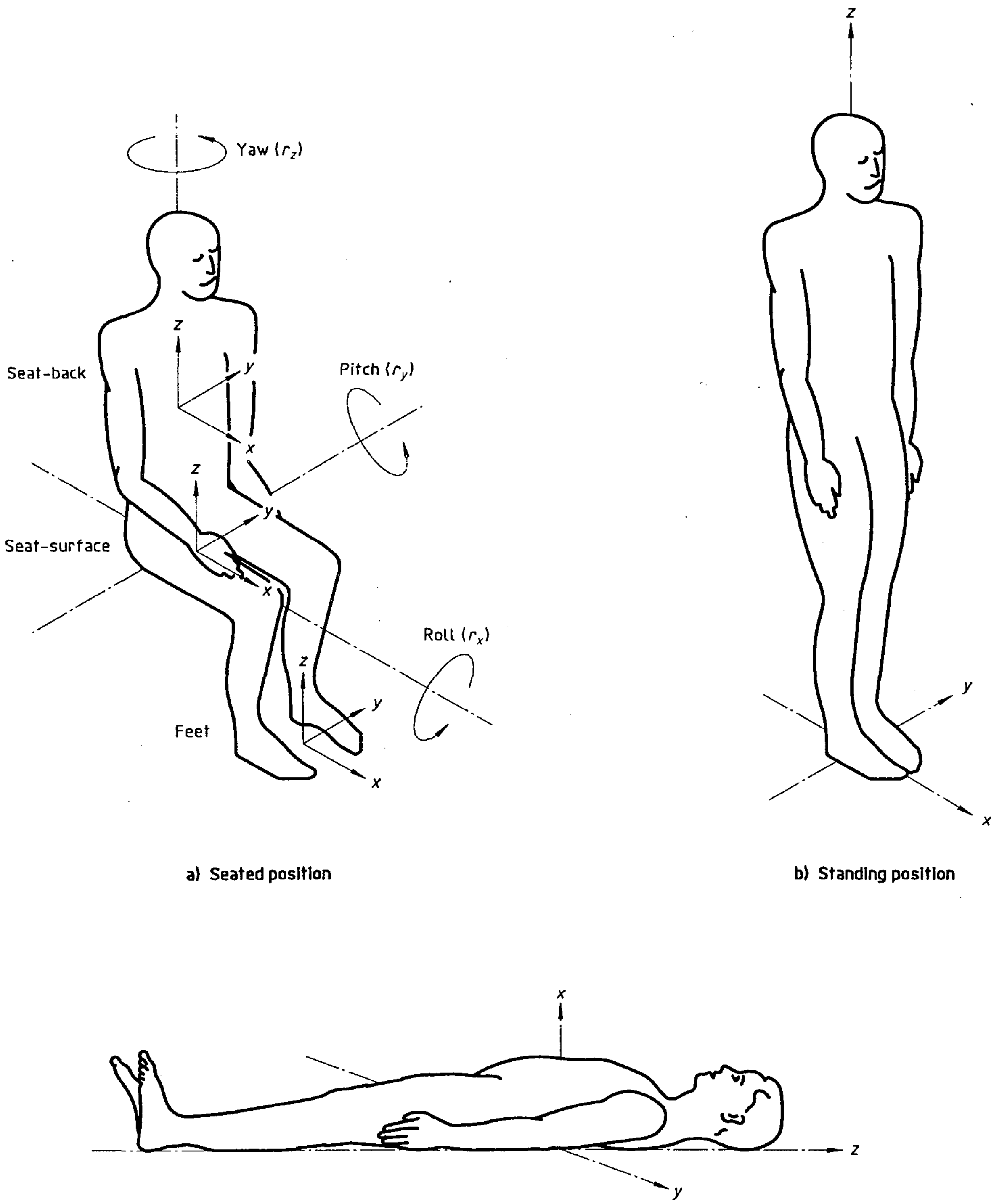
Frequency weighting	Health (see clause 7)	Comfort (see clause 8)	Perception (see clause 8)	Motion sickness (see clause 9)
W_k	*z*-axis, seat surface	*z*-axis, seat surface *z*-axis, standing vertical recumbent (except head) *x*-, *y*-, *z*-axes, feet (sitting)	*z*-axis, seat surface *z*-axis, standing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



a) Seated position

b) Standing position

c) Recumbent position

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/s^2) for translational vibration and radians per second squared (rad/s^2) 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

$$a_w = \left[\frac{1}{T} \int_0^T a_w^2(t)\, dt \right]^{\frac{1}{2}} \qquad \ldots (1)$$

where

$a_w(t)$ is the weighted acceleration (translational or rotational) as a function of time (time history), in metres per second squared (m/s^2) or radians per second squared (rad/s^2), 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.

Table 4 — Additional frequency weightings in one-third octaves

Frequency band number[1)] x	Frequency f Hz	W_c		W_e		W_j	
		factor × 1 000	dB	factor × 1 000	dB	factor × 1 000	dB
−10	0,1	62,4	−24,11	62,5	−24,08	31,0	−30,18
−9	0,125	97,2	−20,25	97,5	−20,22	48,3	−26,32
−8	0,16	158	−16,03	159	−15,98	78,5	−22,11
−7	0,2	243	−12,30	245	−12,23	120	−18,38
−6	0,25	364	−8,78	368	−8,67	181	−14,86
−5	0,315	527	−5,56	536	−5,41	262	−11,65
−4	0,4	708	−3,01	723	−2,81	351	−9,10
−3	0,5	843	−1,48	862	−1,29	417	−7,60
−2	0,63	929	−0,64	939	−0,55	458	−6,78
−1	0,8	972	−0,24	941	−0,53	478	−6,42
0	1	991	−0,08	880	−1,11	484	−6,30
1	1,25	1 000	0,00	772	−2,25	485	−6,28
2	1,6	1 007	0,06	632	−3,99	483	−6,32
3	2	1 012	0,10	512	−5,82	482	−6,34
4	2,5	1 017	0,15	409	−7,77	489	−6,22
5	3,15	1 022	0,19	323	−9,81	524	−5,62
6	4	1 024	0,20	253	−11,93	628	−4,04
7	5	1 013	0,11	202	−13,91	793	−2,01
8	6,3	974	−0,23	160	−15,94	946	−0,48
9	8	891	−1,00	125	−18,03	1 017	0,15
10	10	776	−2,20	100	−19,98	1 030	0,26
11	12,5	647	−3,79	80,1	−21,93	1 026	0,22
12	16	512	−5,82	62,5	−24,08	1 018	0,16
13	20	409	−7,77	50,0	−26,02	1 012	0,10
14	25	325	−9,76	39,9	−27,97	1 007	0,06
15	31,5	256	−11,84	31,6	−30,01	1 001	0,00
16	40	199	−14,02	24,7	−32,15	991	−0,08
17	50	156	−16,13	19,4	−34,24	972	−0,24
18	63	118	−18,53	14,8	−36,62	931	−0,62
19	80	84,4	−21,47	10,5	−39,55	843	−1,48
20	100	56,7	−24,94	7,07	−43,01	708	−3,01
21	125	34,5	−29,24	4,31	−47,31	539	−5,36
22	160	18,2	−34,80	2,27	−52,86	364	−8,78
23	200	9,71	−40,26	1,21	−58,33	243	−12,30
24	250	5,06	−45,92	0,63	−63,99	158	−16,03
25	315	2,55	−51,88	0,32	−69,94	100	−19,98
26	400	1,25	−58,08	0,16	−76,14	62,4	−24,10

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.

6.3.1 The running r.m.s. method

The running r.m.s. evaluation method takes into account occasional shocks and transient vibration by use of a short integration time constant. The vibration magnitude is defined as a maximum transient vibration value (MTVV), given as the maximum in time of $a_w(t_0)$, defined by:

$$a_w(t_0) = \left\{ \frac{1}{\tau} \int_{t_0 - \tau}^{t_0} \left[a_w(t) \right]^2 \, dt \right\}^{\frac{1}{2}} \qquad \ldots (2)$$

where

$a_w(t)$ is the instantaneous frequency-weighted acceleration;

τ is the integration time for running averaging;

t is the time (integration variable);

t_0 is the time of observation (instantaneous time).

This formula defining a linear integration can be approximated by an exponential integration as defined in ISO 8041:

$$a_w(t_0) = \left\{ \frac{1}{\tau} \int_{-\infty}^{t_0} \left[a_w(t) \right]^2 \exp\left[\frac{t - t_0}{\tau} \right] dt \right\}^{\frac{1}{2}} \qquad \ldots (3)$$

The difference in result is very small for application to shocks of a short duration compared to τ, and somewhat larger (up to 30 %) when applied to shocks and transients of longer duration.

The maximum transient vibration value, MTVV, is defined as

$$\mathrm{MTVV} = \max \left[a_w(t_0) \right] \qquad \ldots (4)$$

i.e. the highest magnitude of $a_w(t_0)$ read during the measurement period (T in 6.1).

It is recommended to use $\tau = 1$ s in measuring MTVV (corresponding to an integration time constant, "slow", in sound level meters).

6.3.2 The fourth power vibration dose method

The fourth power vibration dose method is more sensitive to peaks than the basic evaluation method by using the fourth power instead of the second power of the acceleration time history as the basis for averaging. The fourth power vibration dose value (VDV) in metres per second to the power 1,75 ($m/s^{1,75}$), or in radians per second to the power 1,75 ($rad/s^{1,75}$), is defined as:

$$\mathrm{VDV} = \left\{ \int_0^T \left[a_w(t) \right]^4 \, dt \right\}^{\frac{1}{4}} \qquad \ldots (5)$$

where

$a_w(t)$ is the instantaneous frequency-weighted acceleration;

T is the duration of measurement (see 6.1).

NOTE — When the vibration exposure consists of two or more periods, i, of different magnitudes, the vibration dose value for the total exposure should be calculated from the fourth root of the sum of the fourth power of individual vibration dose values:

$$\mathrm{VDV_{total}} = \left(\sum_i \mathrm{VDV}_i^{\,4} \right)^{\frac{1}{4}} \qquad \ldots (6)$$

6.3.3 Ratios used for comparison of basic and additional methods of evaluation

Experience suggests that use of the additional evaluation methods will be important for the judgement of the effects of vibration on human beings when the following ratios are exceeded (depending on which additional method is being used) for evaluating health or comfort:

$$\frac{\mathrm{MTVV}}{a_{\mathrm{w}}} = 1{,}5 \qquad \ldots (7)$$

$$\frac{\mathrm{VDV}}{a_{\mathrm{w}} T^{1/4}} = 1{,}75 \qquad \ldots (8)$$

The basic evaluation method shall be used for the evaluation of the vibration. In cases where one of the additional methods is also used, both the basic evaluation value and the additional evaluation value shall be reported.

6.4 Frequency weighting

6.4.1 Frequency weighting of acceleration time history

For integration of the frequency-weighted acceleration time history, the frequency weighting shall be determined from clause 7, 8 or 9, as appropriate.

The manner in which vibration affects health, comfort, perception and motion sickness is dependent on the vibration frequency content. Different frequency weightings are required for the different axes of vibration. A special frequency weighting is included for evaluation of low-frequency vibration affecting motion sickness.

Two principal frequency weightings, related to health, comfort and perception, are given in table 1:

W_k for the z direction and for vertical recumbent direction (except head);

W_d for the x and y directions and for horizontal recumbent direction.

One principal frequency weighting, related to motion sickness, is given in table 1, designated W_f.

Additional frequency weightings are given in table 2 for the special cases of

- seat-back measurements (W_c);
- measurement of rotational vibration (W_e);
- measurement of vibration under the head of a recumbent person (W_j).

Tables 3 and 4 give the values of the principal and additional frequency weightings. The corresponding frequency weighting curves are shown in figures 2 and 3 respectively.

The frequency weightings may be realised by either analogue or digital methods. They are defined in a mathematical form familiar to filter designers, in annex A.

The frequency weightings given in tables 3 and 4 and illustrated in figures 2 and 3 include the frequency band limitations. In annex A the equations for the frequency band limitation are expressed separately.

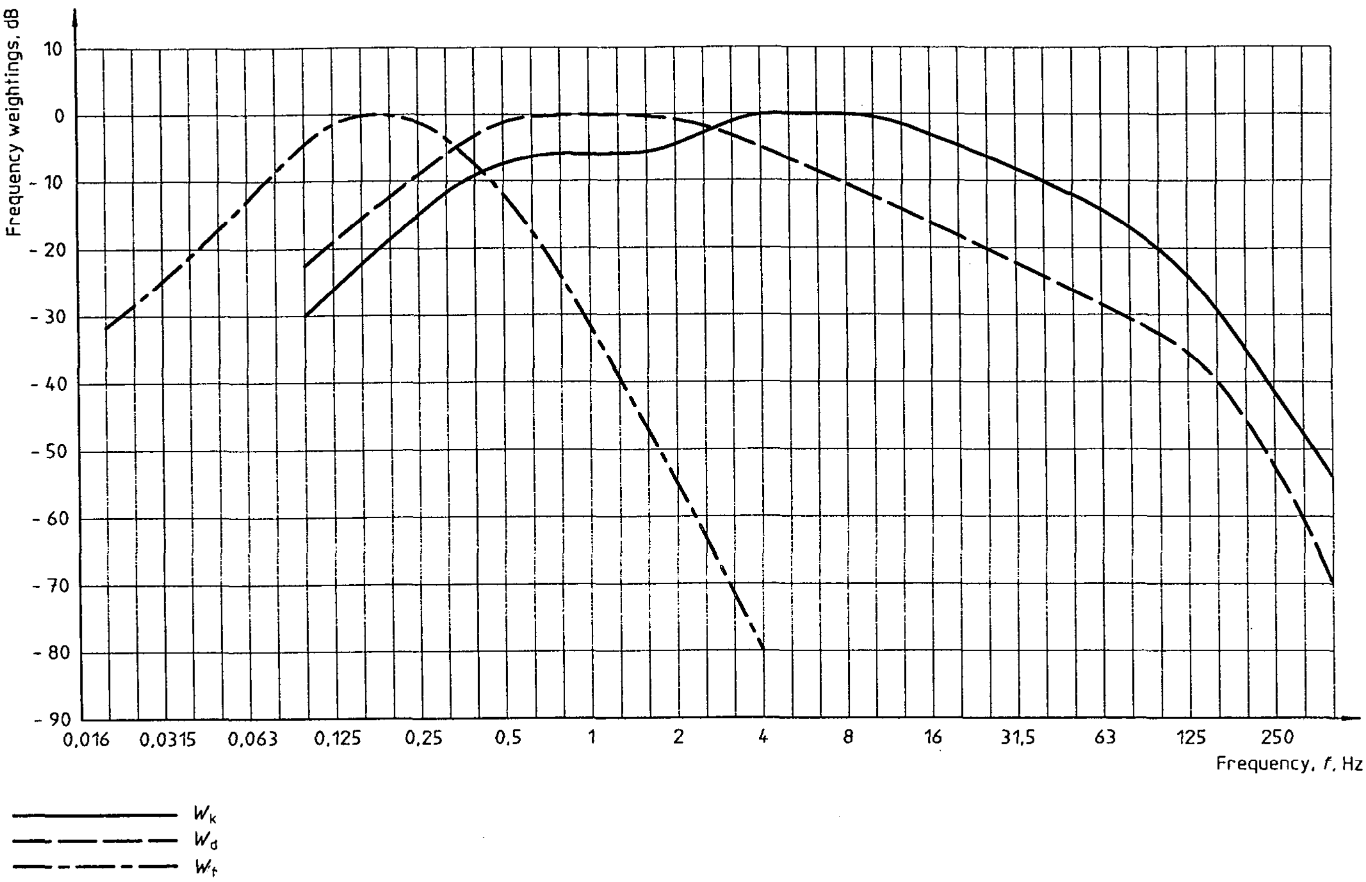


Figure 2 — Frequency weighting curves for principal weightings

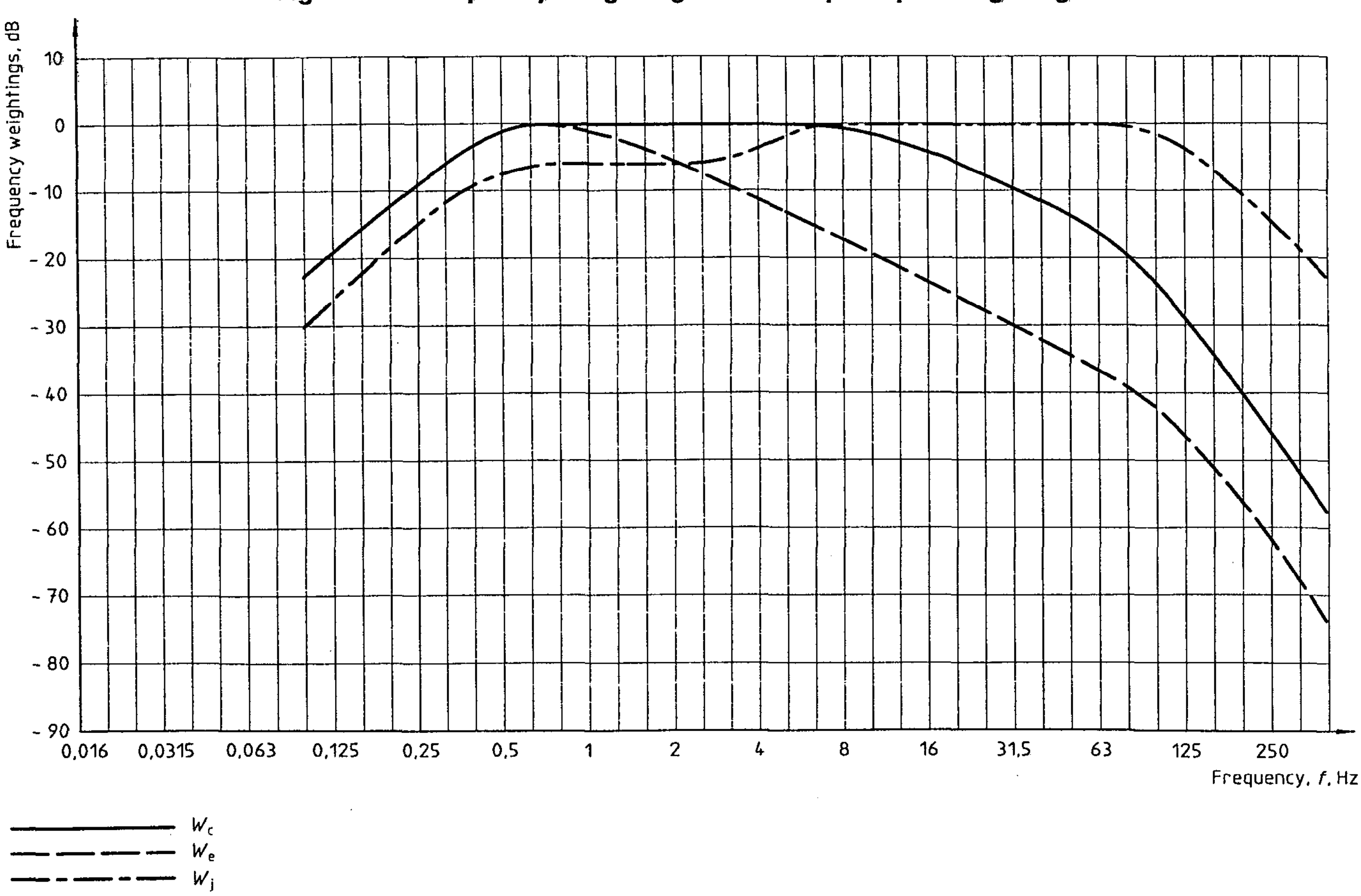


Figure 3 — Frequency weighting curves for additional weightings

6.4.1.1 Frequency band limitation

Lower and upper frequency band limitation shall be achieved by two-pole high-pass and low-pass filters, respectively, with Butterworth characteristics having an asymptotic slope of – 12 dB per octave. The corner frequencies of the band-limiting filters are one-third octave outside the nominal frequency range of the relevant band.

Frequency weightings defined in annex A include the band-limiting filters (high pass at 0,4 Hz and low pass at 100 Hz) to be used with weightings W_c, W_d, W_e, W_j and W_k whereas the frequency weighting W_f has high- and low-pass band-limiting filters at 0,08 Hz and 0,63 Hz, respectively.

6.4.1.2 Tolerances

Within the nominal frequency bands and one-third octave from the frequency limits, the tolerance of the combined frequency weighting and band limiting shall be ± 1 dB. Outside this range, the tolerance shall be ± 2 dB. One octave outside the nominal frequency bands, the attenuation may extend to infinity. (See also ISO 8041 concerning tolerances.)

6.4.2 Frequency weighting of acceleration spectra

The acceleration signal may be analyzed and reported as either constant bandwidth or proportional bandwidth (e.g. as one-third octave band) spectra of unweighted acceleration. In the case of one-third octave bands the centre frequencies shall be as stated in tables 3 and 4. Any form of frequency analysis, analogue or digital, direct one-third octave band or summation of narrow band data may be used. The data analysis method shall be consistent with the one-third octave band filter specification given in IEC 1260.

The frequency-weighted r.m.s. acceleration shall be determined by weighting and appropriate addition of narrow band or one-third octave band data.

For the conversion of one-third octave band data, the weighting factors given in tables 3 and 4 shall be used. The overall weighted acceleration shall be determined in accordance with the following equation or its digital equivalent in the time or frequency domain:

$$a_w = \left[\sum_i (W_i a_i)^2 \right]^{\frac{1}{2}} \qquad \ldots (9)$$

where

a_w is the frequency-weighted acceleration;

W_i is the weighting factor for the i th one-third octave band given in tables 3 and 4;

a_i is the r.m.s. acceleration for the i th one-third octave band.

6.5 Combining vibrations in more than one direction

The vibration total value of weighted r.m.s. acceleration, determined from vibration in orthogonal coordinates is calculated as follows:

$$a_v = \left(k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2 \right)^{\frac{1}{2}} \qquad \ldots (10)$$

where

a_{wx}, a_{wy}, a_{wz} are the weighted r.m.s. accelerations with respect to the orthogonal axes x, y, z, respectively;

k_x, k_y, k_z are multiplying factors.

The use of the vibration total value, a_v, is recommended for comfort (see 8.2).

NOTES
1 The exact value of the multiplying factors applied depends on the frequency weighting selected and are specified in clauses 7 and 8.
2 The vibration total value or vector sum have also been proposed for evaluation with respect to health and safety if no dominant axis of vibration exists.

6.6 Guide to the use of the vibration evaluation methods

Guidance with respect to the use of the various evaluation methods and frequency weightings is given in clause 7 for health, clause 8 for comfort and perception and clause 9 for motion sickness. Annexes B, C and D give further information on the interpretation of measured values with respect to health, comfort and perception, and motion sickness.

7 Health

7.1 Application

This clause concerns the effects of periodic, random and transient vibration on the health of persons in normal health exposed to whole-body vibration during travel, at work and during leisure activities. It applies primarily to seated persons, since the effects of vibration on the health of persons standing, reclining or recumbent are not known.

The guidance is applicable to vibration in the frequency range 0,5 Hz to 80 Hz which is transmitted to the seated body as a whole through the seat pan.

NOTE — If it has been established that the frequency range below 1 Hz is not relevant nor important, a frequency range from 1 Hz to 80 Hz can be substituted.

The relevant literature on the effects of long-term high-intensity whole-body vibration indicates an increased health risk to the lumbar spine and the connected nervous system of the segments affected. This may be due to the biodynamic behaviour of the spine: horizontal displacement and torsion of the segments of the vertebral column. Excessive mechanical stress and/or disturbances of nutrition of and diffusion to the disc tissue may contribute to degenerative processes in the lumbar segments (spondylosis deformans, osteochondrosis intervertebralis, arthrosis deformans). Whole-body vibration exposure may also worsen certain endogenous pathologic disturbances of the spine. Although a dose-effect relationship is generally assumed, there is at present no quantitative relationship available.

With a lower probability, the digestive system, the genital/urinary system, and the female reproductive organs are also assumed to be affected.

It generally takes several years for health changes caused by whole-body vibration to occur. It is therefore important that exposure measurements are representative of the whole exposure period.

7.2 Evaluation of the vibration

7.2.1 The weighted r.m.s. acceleration (see 6.1) shall be determined for each axis (x, y and z) of translational vibration on the surface which supports the person.

7.2.2 The assessment of the effect of a vibration on health shall be made independently along each axis. The assessment of the vibration shall be made with respect to the highest frequency-weighted acceleration determined in any axis on the seat pan.

NOTE — When vibration in two or more axes is comparable, the vector sum is sometimes used to estimate health risk.

7.2.3 The frequency weightings shall be applied for seated persons as follows with the multiplying factors k as indicated

x-axis: W_d, $k = 1,4$

y-axis: W_d, $k = 1,4$

z-axis: W_k, $k = 1$

NOTE — Measurements in the x-axis on the backrest using frequency weighting W_c with $k = 0,8$ are encouraged. However, considering the shortage of evidence showing the effect of this motion on health it is not included in the assessment of the vibration severity given in annex B.

7.3 Guidance on the effects of vibration on health

Guidance on the effects of vibration on health can be found in annex B.

8 Comfort and perception

8.1 Application

This clause concerns the estimation of the effect of vibration on the comfort of persons in normal health who are exposed to whole-body periodic, random and transient vibration during travel, at work or during leisure activities.

For the comfort of seated persons this clause applies to periodic, random and transient vibration in the frequency range 0,5 Hz to 80 Hz which occurs in all six axes on the seat pan (three translational: x-axis, y-axis and z-axis and three rotational: r_x-axis, r_y-axis and r_z-axis). It also applies to the three translational axes (x, y and z) at the seat-back and feet of seated persons (see figure 1).

For the comfort of standing and recumbent persons guidance is provided for periodic, random and transient vibration occurring in the three translational (x, y and z) axes on the principal surface supporting the body.

The evaluation procedures make it possible to estimate (from the vibration magnitude, frequency and direction) the likely relative effects on comfort of different types of vibration.

NOTE — For specific applications, other standards may include an appropriate time dependence of vibration magnitude and duration.

8.2 Comfort

8.2.1 There is no conclusive evidence to support a universal time dependence of vibration effects on comfort.

The weighted r.m.s. acceleration (see clause 6) shall be determined for each axis of translational vibration (x-, y- and z-axes) at the surface which supports the person.

NOTE — When the vibration conditions are fluctuating (as in rail vehicles, for example) comfort may also be assessed from statistics derived from distributions of r.m.s. values of appropriately frequency-weighted signals.

8.2.2 Frequency weightings used for the prediction of the effects of vibration on comfort are W_c, W_d, W_e, W_j and W_k. These weightings should be applied as follows with the multiplying factors k as indicated.

8.2.2.1 For seated persons:

x-axis (supporting seat surface vibration): W_d, $k = 1$

y-axis (supporting seat surface vibration): W_d, $k = 1$

z-axis (supporting seat surface vibration): W_k, $k = 1$

NOTES

1 For specific design purposes regarding comfort, special appropriate weighting curves based on experience may be used for specific applications.

2 A further part to this International Standard (currently in preparation) on the application on railway vehicles uses another weighting curve for comfort, designated W_b (see C.2.2.1).

3 In some environments, the comfort of a seated person may be affected by rotational vibration on the seat, by vibration of the backrest or by vibration at the feet. Vibration at these positions may be assessed using the following frequency weightings:

r_x-axis on supporting seat surface:	W_e, k = 0,63 m/rad
r_y-axis on supporting seat surface:	W_e, k = 0,4 m/rad
r_z-axis on supporting seat surface:	W_e, k = 0,2 m/rad
x-axis on the backrest:	W_c, k = 0,8
y-axis on the backrest:	W_d, k = 0,5
z-axis on the backrest:	W_d, k = 0,4
x-axis at the feet:	W_k, k = 0,25
y-axis at the feet:	W_k, k = 0,25
z-axis at the feet:	W_k, k = 0,4

where k is the multiplying factor.

The multiplying factors for rotational vibration have the dimension metres per radian (m/rad) in order to be applied in accordance with note 2 in 8.2.3.

8.2.2.2 For standing persons:

x-axis (floor vibration):	W_d, k = 1
y-axis (floor vibration):	W_d, k = 1
z-axis (floor vibration):	W_k, k = 1

8.2.2.3 For recumbent persons, when measuring under the pelvis:

horizontal axes:	W_d, k = 1
vertical axis:	W_k, k = 1

NOTE — When there is no soft pillow, it is recommended to measure also beneath the head and use frequency weighting W_j with k = 1, although no specific guidance on the use of this measurement for prediction of comfort/perception is being included in annex C.

8.2.3 Vibration in more than one direction and more than one point

Measurements shall normally include all relevant translational directions and may include more than one point affecting the comfort. The weighted values in every axis measured at each measurement point shall be reported separately.

For each measurement point the point vibration total value shall then be calculated by a root-sum-of-squares summation, see 6.5. The point vibration total values may be compared separately with similarly defined values in other environments and with any specifications (e.g. limits) for the system.

Where the comfort is affected by vibrations in more than one point an overall vibration total value can be determined from the root-sum-of-squares of the point vibration total values (e.g. translation on the seat and at the back and feet).

NOTES

1 In some environments there may be combinations of sitting, standing and recumbent persons. It may then be necessary to consider the effect of all positions and postures (see ISO 2631-2).

2 In some cases rotational vibrations are of importance in comfort assessment. In such cases the rotational point vibration total value may be included in the root-sum-of-squares when calculating the overall vibration total value [the rotational point vibration total value can be calculated by an expression similar to that of equation (10)].

3 If the weighted value determined in any axis (or rotational direction) is less than 25 % of the maximum value determined at the same point but in another axis (or rotational direction) it can be excluded. Similarly, if the point vibration total value in one point is less than 25 % of the point vibration total value which is maximum, it can be excluded.

4 Horizontal vibration at the backrest in vehicles can significantly affect the comfort. If for technical reasons the vibration on the backrest cannot be measured, a multiplying factor equal to 1,4 should be used instead of 1 for x- and y-axes on the supporting seat surface to estimate the comfort.

8.3 Perception

8.3.1 Application

For the perception of vibration by standing, sitting and recumbent persons, guidance is provided for periodic and random vibration occurring in the three translational (x, y and z) axes on the principal surface supporting the body.

8.3.2 Evaluation of the vibration

The weighted r.m.s. acceleration (see 6.1) shall be determined for each axis (x, y and z) on the principal surface supporting the body.

The assessment of the perceptibility of the vibration shall be made with respect to the highest weighted r.m.s. acceleration determined in any axis at any point of contact at any time.

8.3.3 Frequency weighting

Two frequency weightings, W_k for vertical vibration and W_d for horizontal vibration, are used for the prediction of the perceptibility of vibration. These weightings may be applied to the following combinations of posture and vibration axes:

x-, y- and z-axes on a supporting seat surface for sitting person,	$k = 1$
x-, y- and z-axes on a floor beneath a standing person,	$k = 1$
x-, y- and z-axes on a surface supporting a recumbent person (except head),	$k = 1$

NOTE — The reporting of unweighted r.m.s. acceleration values in addition to the weighted values is encouraged.

8.4 Guidance on the effects of vibration on perception and comfort

Guidance on the effects of vibration on perception and comfort can be found in annex C.

9 Motion sickness

9.1 Application

This clause concerns the effects of oscillatory motion on the incidence of kinetosis, or motion sickness.

Other clauses of this part of ISO 2631 are primarily concerned with vibration at frequencies above 0,5 Hz. Motion at frequencies below 0,5 Hz may cause various undesirable effects including discomfort and interference with activities. However, most commonly, it can produce motion sickness, primarily in the standing and sitting postures.

The methods presented here should be primarily applicable to motion in ships and other sea vessels.

9.2 Evaluation of the vibration

9.2.1 The weighted r.m.s. acceleration shall be determined for the z-axis vibration at the surface which supports the person, at frequencies between 0,1 Hz and 0,5 Hz.

NOTE — The crest factor of low-frequency motions (i.e. after frequency weighting according to 6.2.1) is such that in all cases, the r.m.s. acceleration of the motion should be determined by true integration and reported.

9.2.2 The vibration shall be assessed only with respect to the overall weighted acceleration in the z-axis.

NOTES

1 There is some evidence that roll and pitch motions of the body (see figure 1) may also contribute to motion sickness symptoms. When sufficient data on the effects of other directions become available a summation procedure for all directions may be indicated.

2 At low frequencies the motion of all parts of the body will tend to be similar. However, voluntary and involuntary head movements will often occur. It is currently assumed that motion sickness may be reduced by reduction of such head motions. In practice this will usually be achieved by holding, or resting, the head against a structure moving with the seat (e.g. headrest).

3 The guidance given in this clause is only applicable to persons in sitting and standing postures. It is possible that the probability of motion sickness may be reduced in recumbent postures. It is not clear whether this arises because vertical motion is then in the x-axis of the body or because less head motion occurs in this position.

9.2.3 Frequency weighting

A single frequency weighting, W_f, is recommended for the evaluation of the effects of vibration on the incidence of motion sickness.

NOTES

1 It is recommended that additional information about the motion conditions also be reported. This should include the frequency composition, duration and directions of motions.

2 There is some evidence that motions having similar frequencies and r.m.s. accelerations but different waveforms may have different effects.

9.3 Guidance on the effects of vibration on the incidence of motion sickness

Guidance on the effects of vibration on motion sickness can be found in annex D.

Annex A
(normative)

Mathematical definition of the frequency weightings

A.1 Parameters of the transfer functions

The parameters of the transfer functions are given in tables A.1 and A.2.

Table A.1 — Parameters of the transfer functions of the principal frequency weightings

Weighting	Band-limiting		Acceleration-velocity transition (a-v transition)			Upward step			
	f_1 Hz	f_2 Hz	f_3 Hz	f_4 Hz	Q_4	f_5 Hz	Q_5	f_6 Hz	Q_6
W_k	0,4	100	12,5	12,5	0,63	2,37	0,91	3,35	0,91
W_d	0,4	100	2,0	2,0	0,63	∞	—	∞	—
W_f	0,08	0,63	∞	0,25	0,86	0,062 5	0,80	0,1	0,80

Table A.2 — Parameters of the transfer functions of the additional frequency weightings

Weighting	Band-limiting		Acceleration-velocity transition (a-v transition)			Upward step			
	f_1 Hz	f_2 Hz	f_3 Hz	f_4 Hz	Q_4	f_5 Hz	Q_5	f_6 Hz	Q_6
W_c	0,4	100	8,0	8,0	0,63	∞	—	∞	—
W_e	0,4	100	1,0	1,0	0,63	∞	—	∞	—
W_j	0,4	100	∞	∞	—	3,75	0,91	5,32	0,91

A.2 Transfer functions

The frequencies f_1, ..., f_6 and the resonant quality factors Q_4, ..., Q_6 are parameters of the transfer function which determine the overall frequency weighting (referred to acceleration as the input quantity). The transfer function is expressed as a product of several factors as follows.

Band-limiting (two-pole filter with Butterworth characteristic, $Q_1 = Q_2 = 1/\sqrt{2}$):

High pass;

$$\left|H_h(p)\right| = \left|\frac{1}{1+\sqrt{2}\,\omega_1/p+(\omega_1/p)^2}\right| = \sqrt{\frac{f^4}{f^4+f_1^4}} \qquad \text{... (A.1)}$$

where

$\omega_1 = 2\pi f_1$;

f_1 = corner frequency (intersection of asymptotes).

Low pass;

$$\left|H_l(p)\right| = \left|\frac{1}{1+\sqrt{2}\,p/\omega_2 + (p/\omega_2)^2}\right| = \sqrt{\frac{f_2^4}{f^4+f_2^4}} \qquad \text{..(A.2)}$$

where

$\omega_2 = 2\,\pi f_2$;

f_2 = corner frequency.

Acceleration-velocity transition (proportionality to acceleration at lower frequencies, proportionality to velocity at higher frequencies):

$$\left|H_t(p)\right| = \left|\frac{1+p/\omega_3}{1+p/(Q_4\omega_4)+(p/\omega_4)^2}\right| = \sqrt{\frac{f^2+f_3^2}{f_3^2}}\cdot\sqrt{\frac{f_4^4\cdot Q_4^2}{f^4\cdot Q_4^2+f^2\cdot f_4^2\left(1-2Q_4^2\right)+f_4^4\cdot Q_4^2}} \qquad \text{...(A.3)}$$

where

$\omega_3 = 2\,\pi f_3$;

$\omega_4 = 2\,\pi f_4$.

Upward step (steepness approximately 6 dB per octave, proportionality to jerk):

$$\left|H_s(p)\right| = \left|\frac{1+p/(Q_5\omega_5)+(p/\omega_5)^2}{1+p/(Q_6\omega_6)+(p/\omega_6)^2}\cdot\left(\frac{\omega_5}{\omega_6}\right)^2\right| = \frac{Q_6}{Q_5}\cdot\sqrt{\frac{f^4\cdot Q_5^2+f^2\cdot f_5^2\left(1-2Q_5^2\right)+f_5^4\cdot Q_5^2}{f^4\cdot Q_6^2+f^2\cdot f_6^2\left(1-2Q_6^2\right)+f_6^4\cdot Q_6^2}} \qquad \text{...(A.4)}$$

where

$\omega_5 = 2\,\pi f_5$;

$\omega_6 = 2\pi f_6$.

The product $H_h(p)\cdot H_l(p)$ represents the band-limiting transfer function; it is the same for all weightings except W_f.

The product $H_t(p)\cdot H_s(p)$ represents the actual weighting transfer function for a certain application.

$H_t(p) = 1$ for weighting W_j;

$H_s(p) = 1$ for weightings W_c, W_d and W_e.

This is indicated by infinity frequencies and absence of quality factors in the tables.

The total weighting function is

$$H(p) = H_h(p)\cdot H_l(p)\cdot H_t(p)\cdot H_s(p) \qquad \text{...(A.5)}$$

In the most common interpretation of this equation (in the frequency domain) it describes the modulus (magnitude) and phase in the form of a complex number as a function of the imaginary angular frequency, $p = j2\pi f$.

NOTE — Sometimes the symbol s is used instead of p. If the equation is interpreted in the time domain $\frac{d}{dt}$ (differential operator), it leads directly to the digital realization of the weighting ($\frac{d}{dt}$ approximated by $\frac{\Delta}{\Delta t}$ if the sampling interval Δt is small enough). Alternatively p may be interpreted as the variable of the Laplace transform.

The weighting curves in figures 2 and 3 show the modulus (magnitude) $|H|$ of H versus the frequency f in a double-logarithmic scale.

Annex B
(informative)

Guide to the effects of vibration on health

B.1 Introduction

The annex provides guidance for the assessment of whole-body vibration with respect to health. It applies to people in normal health who are regularly exposed to vibration. It applies to rectilinear vibration along the *x*-, *y*- and *z*-basicentric axes of the human body. It does not apply to high magnitude single transients such as may result from vehicle accident and cause trauma.

NOTE — Most of the guidance in this annex is based upon data available from research on human response to *z*-axis vibration of seated persons. There is only limited experience in applying this part of ISO 2631 for *x*-, *y*-axes seating and for all axes of standing, reclining and recumbent positions.

B.2 Basis for health guidance

Biodynamic research as well as epidemiological studies have given evidence for an elevated risk of health impairment due to long-term exposure with high-intensity whole-body vibration. Mainly the lumbar spine and the connected nervous system may be affected. Metabolic and other factors originating from within may have an additional effect on the degeneration. It is sometimes assumed that environmental factors such as body posture, low temperature, and draught can contribute to muscle pain. However, it is unknown if these factors can contribute to the degeneration of discs and vertebrae.

Increased duration (within the working day or daily over years) and increased vibration intensity mean increased vibration dose and are assumed to increase the risk, while periods of rest can reduce the risk.

There are not sufficient data to show a quantitative relationship between vibration exposure and risk of health effects. Hence, it is not possible to assess whole-body vibration in terms of the probability of risk at various exposure magnitudes and durations.

B.3 Assessment of vibration

B.3.1 Use of weighted r.m.s. acceleration

Assuming responses are related to energy, two different daily vibration exposures are equivalent when:

$$a_{w1} \cdot T_1^{1/2} = a_{w2} \cdot T_2^{1/2} \qquad \text{... (B.1)}$$

where

a_{w1} and a_{w2} are the weighted r.m.s. acceleration values for the first and second exposures, respectively;

T_1 and T_2 are the corresponding durations for the first and second exposures.

A health guidance caution zone is indicated by dashed lines in figure B.1.

For exposures below the zone, health effects have not been clearly documented and/or objectively observed; in the zone, caution with respect to potential health risks is indicated and above the zone health risks are likely. This recommendation is mainly based on exposures in the range of 4 h to 8 h as indicated by the shading in figure B.1. Shorter durations should be treated with extreme caution.

Other studies indicate a time dependence according to the following relationship:

$$a_{w1} \cdot T_1^{1/4} = a_{w2} \cdot T_2^{1/4} \qquad \text{... (B.2)}$$

This health guidance caution zone is indicated by dotted lines in figure B.1. (The health guidance caution zones for equations (B.1) and (B.2) are the same for durations from 4 h to 8 h for which most occupational observations exist.)

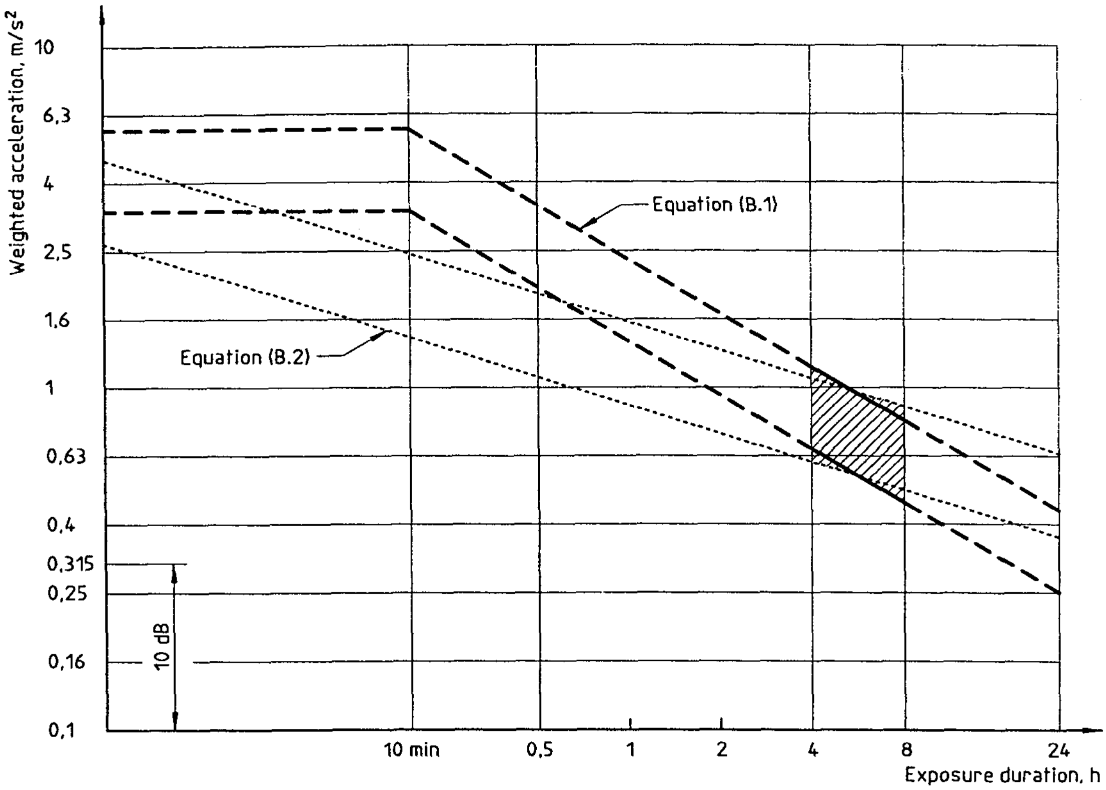


Figure B.1 — Health guidance caution zones

The r.m.s. value of the frequency-weighted acceleration can be compared with the zone shown in figure B.1 at the duration of the expected daily exposure.

To characterize daily occupational vibration exposure, the 8 h frequency-weighted acceleration a_w can be measured or calculated according to the formula in 6.1 with 8 h as the time period T.

NOTES

1 When the vibration exposure consists of two or more periods of exposure to different magnitudes and durations, the energy-equivalent vibration magnitude corresponding to the total duration of exposure can be evaluated according to the following formula:

$$a_{w,e} = \left[\frac{\sum a_{wi}^2 \cdot T_i}{\sum T_i} \right]^{\frac{1}{2}} \qquad \text{... (B.3)}$$

where

$a_{w,e}$ is the equivalent vibration magnitude (r.m.s. acceleration in m/s²);

a_{wi} is the vibration magnitude (r.m.s. acceleration in m/s²) for exposure duration T_i.

Some studies indicates a different equivalent vibration magnitude given by the formula:

$$a_{w,e} = \left[\frac{\sum a_{wi}^4 \cdot T_i}{\sum T_i} \right]^{\frac{1}{4}} \quad \ldots \text{(B.4)}$$

These two equivalent vibration magnitudes have been used for health guidance according to figure B.1.

2 An estimated vibration dose value (eVDV) has been used in some studies:

$$\text{eVDV} = 1{,}4\, a_w T^{1/4} \quad \ldots \text{(B.5)}$$

where

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

T is the exposure duration, in seconds.

The estimated vibration dose values corresponding to the lower and upper bounds of the zone given by equation (B.2) in figure B.1 are 8,5 and 17, respectively.

B.3.2 Method of assessment when the basic evaluation method is not sufficient

Health disorders are currently understood to be influenced by peak values and are possibly underestimated by methods involving r.m.s. averaging alone.

Therefore, for some environments for example when the crest factor is above 9 (see 6.2.1 and 6.3.3), the method presented in 6.3.1 and 6.3.2 of this part of ISO 2631 may be applied.

NOTE — It is recognized that the crest factor is an uncertain method of deciding whether r.m.s. acceleration can be used to assess human response to vibration. In case of doubt it is recommended to use the criteria described in 6.3.3.

Annex C
(informative)

Guide to the effects of vibration on comfort and perception

C.1 Introduction

This annex indicates the current consensus of opinion on the relationship between the vibration magnitude and human comfort. The annex is concerned with providing a uniform and convenient method of indicating the subjective severity of the vibration but does not present limits.

C.2 Comfort

C.2.1 Environmental context

A particular vibration condition may be considered to cause unacceptable discomfort in one situation but may be classified as pleasant or exhilarating in another. Many factors combine to determine the degree to which discomfort may be noted or tolerated. An accurate assessment of the acceptability of the vibration, and the formulation of vibration limits can only be made with the knowledge of many factors. Comfort expectations and annoyance tolerance are quite different in transportation vehicles compared to commercial or residential buildings.

Interference with activities (e.g. reading, writing and drinking) due to vibration may sometimes be considered a cause of discomfort. These effects are often highly dependant on the detail of the activity (e.g. support used for the writing and container used for drinking) and are not within the scope of the guidance given here.

C.2.2 Assessment of vibration

C.2.2.1 Use of weighted r.m.s. acceleration

For some environments it is possible to evaluate the effects of vibration on human comfort by using the frequency-weighted r.m.s. acceleration (weighted according to tables 1 and 2) of a representative period.

NOTE — For the evaluation of comfort in some environments, e.g. rail vehicles, a frequency weighting, designated W_b, deviating slightly, primarily below 4 Hz from W_k, is considered the appropriate weighting curve, primarily for the z direction (see note 2 in 8.2.2.1). Frequency weighting W_b may be used as an acceptable approximation to W_k in spite of its deviation from W_k below 5 Hz and above 10 Hz (refer to table A.1: f_3 and f_4 would be 16 Hz for W_b compared to 12,5 Hz for W_k).

C.2.2.2 Comparison with guidance

The r.m.s. value of the frequency-weighted acceleration can be compared with the guidance shown in C.2.3.

NOTES

1 When the vibration exposure consists of two or more periods of exposure to different magnitudes and durations, the equivalent vibration magnitude corresponding to the total duration of exposure can be evaluated according to either one of the formulae:

$$a_{w,e} = \left[\frac{\sum a_{wi}^2 \cdot T_i}{\sum T_i} \right]^{\frac{1}{2}} \qquad \text{... (C.1)}$$

or

$$a_{w,e} = \left[\frac{\sum a_{wi}^4 \cdot T_i}{\sum T_i} \right]^{\frac{1}{4}} \qquad \text{... (C.2)}$$

where

$a_{w,e}$ is the equivalent vibration magnitude (r.m.s. acceleration in m/s²);

a_{wi} is the vibration magnitude (r.m.s. acceleration in m/s²) for exposure duration T_i.

2 Although, as stated in 8.2.1, there is no conclusive evidence to support a time dependency of vibration on comfort, the frequency-weighted r.m.s. acceleration has been used to calculate the dose of vibration which will be received during an expected daily exposure. This estimated vibration dose value in metres per second to the power 1,75 ($m/s^{1,75}$) is given by:

$$\text{eVDV} = 1{,}4\, a_w T^{1/4} \qquad \text{... (C.3)}$$

where

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

T is the exposure duration, in seconds.

The estimated vibration dose value obtained by this procedure may be compared with that obtained from an alternative environment so as to compare the discomfort of the two environments.

C.2.2.3 Method of assessment when the basic evaluation method is not sufficient

For some environments, for example when the crest factor is above 9, it is not possible to evaluate human response to vibration using the frequency-weighted r.m.s. acceleration. Discomfort can be significantly influenced by peak values and underestimated by methods involving r.m.s. averaging. In these cases the measures described in 6.3 shall be applied.

Vibration values obtained in one environment may be compared with those obtained in another environment so as to compare the discomfort.

NOTE — It is recognized that the crest factor is an uncertain method of deciding whether r.m.s. acceleration can be used to assess human response to vibration. In case of doubt see 6.3.3.

C.2.3 Comfort reactions to vibration environments

Acceptable values of vibration magnitude for comfort in accordance with 8.2 depend on many factors which vary with each application. Therefore, a limit is not defined in this part of ISO 2631. The following values give approximate indications of likely reactions to various magnitudes of overall vibration total values in public transport.

However, as stated before, the reactions at various magnitudes depend on passenger expectations with regard to trip duration and the type of activities passengers expect to accomplish (e.g. reading, eating, writing, etc.) and many other factors (acoustic noise, temperature, etc.).

Less than 0,315 m/s²:	not uncomfortable
0,315 m/s² to 0,63 m/s²:	a little uncomfortable
0,5 m/s² to 1 m/s²:	fairly uncomfortable
0,8 m/s² to 1,6 m/s²:	uncomfortable
1,25 m/s² to 2,5 m/s²:	very uncomfortable
Greater than 2 m/s²:	extremely uncomfortable

With respect to comfort and/or discomfort reactions to vibration in residential and commercial buildings, ISO 2631-2 should be consulted. Experience in many countries has shown that occupants of residential buildings are likely to complain if the vibration magnitudes are only slightly above the perception threshold.

C.3 Perception

Fifty percent of alert, fit persons can just detect a W_k weighted vibration with a peak magnitude of 0,015 m/s^2.

There is a large variation between individuals in their ability to perceive vibration. When the median perception threshold is approximately 0,015 m/s^2, the interquartile range of responses may extend from about 0,01 m/s^2 to 0,02 m/s^2 peak.

The perception threshold decreases slightly with increases in vibration duration up to one second and very little with further increases in duration. Although the perception threshold does not continue to decrease with increasing duration, the sensation produced by vibration at magnitudes above threshold may continue to increase.

Annex D
(informative)

Guide to the effects of vibration on the incidence of motion sickness

D.1 Duration of vibration

The probability of occurrence of motion sickness symptoms increases with increasing duration of motion exposure up to several hours. Over longer periods (a few days) adaptation (i.e. lowered sensitivity) to the motion occurs. Some adaptation may be retained so as to reduce the probability of motion sickness due to similar motions on a future occasion.

A motion sickness dose value is defined such that higher values correspond to a greater incidence of motion sickness.

There are two alternative methods of calculating the motion sickness dose value:

a) Where possible, the motion sickness dose value should be determined from motion measurements throughout the full period of exposure. The motion sickness dose value $MSDV_z$, in metres per second to the power 1,5 ($m/s^{1,5}$), is given by the square root of the integral of the square of the z-axis acceleration after it has been frequency-weighted:

$$MSDV_z = \left\{ \int_0^T [a_w(t)]^2 \, dt \right\}^{\frac{1}{2}} \qquad \text{... (D.1)}$$

where

$a_w(t)$ is the frequency-weighted acceleration in the z direction;

T is the total period (in seconds) during which motion could occur.

This method is equivalent to calculating the r.m.s. value by true integration over the period T and multiplying by $T^{1/2}$.

b) If the motion exposure is continuous and of approximately constant magnitude, the motion sickness dose value may be estimated from the frequency-weighted r.m.s. value determined over a short period. The motion sickness dose value, $MSDV_z$, in metres per second to the power 1,5 ($m/s^{1,5}$), for the exposure duration, T_0, in seconds, is found by multiplying the square of the measured r.m.s. z-axis acceleration, a_w, by the exposure duration, T_0, and taking the square root:

$$MSDV_z = a_w \, T_0^{1/2} \qquad \text{... (D.2)}$$

NOTE — When using method b) above, the measurement period should not normally be less than 240 s.

D.2 Guide to effect of motion sickness dose values

There are large differences in the susceptibility of individuals to the effects of low-frequency oscillation. It has been found that females are more prone to motion sickness than males and that the prevalence of symptoms declines with increasing age. The percentage of people who may vomit is approximately $K_m \cdot MSDV_z$ where K_m is a constant which may vary according to the exposed population, but, for a mixed population of unadapted male and female adults, K_m = 1/3. These relationships are based on exposures to motion lasting from about 20 min to about 6 h with the prevalence of vomiting varying up to about 70 %.

NOTE — In some cases, the percentage of persons who may vomit may exceed the value calculated by the above formula when a_w exceeds 0,5 m/s^2.

Annex E
(informative)

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