INTERNATIONAL STANDARD

ISO 8041

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AMENDMENT 1
1999-11-01

Human response to vibration — Measuring instrumentation

AMENDMENT 1

Réponse des individus aux vibrations — Appareillage de mesure

AMENDEMENT 1

Reference number
ISO 8041:1990/Amd.1:1999(E)

Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

Amendment 1 to ISO 8041:1990 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

This amendment is a result of the resolution taken by ISO/TC 108/SC 3, September 1995, to revise ISO 8041:1990. In this first step, ISO 8041 is made compatible with the revised ISO 2631-1.

This amendment specifies instrumentation characteristics for measurement of whole-body vibration in accordance with redefined frequency weightings and alternative evaluation procedures introduced in ISO 2631-1:1997. Specification, calibration and verification tests for instrumentation have not been agreed for all evaluation procedures and these will be addressed in a future revision of ISO 8041.

The instrumentation specifications for measurement according to ISO 5349 (hand-arm) and ISO 2631-2 (whole-body combined) vibration are unchanged. However, data for these frequency weightings are now presented in the style used throughout this amendment.

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AMENDMENT 1

Page 1

2 Normative references

Add year of publication, 1990, to ISO 2041.

Change year of publication of ISO 2631-1 to 1997 and change the title to *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements.*

Change year of publication of ISO 5805 to 1997 and change title to *Mechanical vibration and shock — Human exposure — Vocabulary.*

Delete ISO 2631-3.

Replace the two lines concerning IEC 225 by:

IEC 61260:1995, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 60651:1979, *Electroacoustics — Sound level meters*

IEC 60651:1979/Amd.1:1993, Amendment 1.

Page 2

3.1 weighted vibration

Replace first paragraph on page 2 by:

> The acceleration is weighted in accordance with one of the eight frequency weightings listed in table 1 and specified in tables 4 to 11. Exact definitions are presented in annex B.

Replace table 1 by the following table:

Table 1 — Frequency weightings

Characteristics of vibration	**Nominal frequency range** Hz	**International Standard**
Whole-body vibration:		
Principal weightings:		
Whole body, vertical direction z, designated W_k	0,5 to 80	ISO 2631-1:1997
Whole body, horizontal directions x, y, designated W_d	0,5 to 80	ISO 2631-1:1997
Whole body, motion sickness, vertical direction z, designated W_f	0,1 to 0,5	ISO 2631-1:1997
Whole body, combined directions, designated W.B.combined	1 to 80	ISO 2631-2:1989
Additional weightings:		
Whole body, seat back horizontal direction x, designated W_c	0,5 to 80	ISO 2631-1:1997
Whole body, rotational vibration r_x, r_y, r_z, designated W_e	0,5 to 80	ISO 2631-1:1997
Head of recumbent person, vertical direction x, designated W_j	0,5 to 80	ISO 2631-1:1997
Hand-arm vibration:		
All directions x, y, z, designated W_h	8 to 1000	ISO 5349:1986

NOTE Additional applications of the frequency weightings are described in ISO 2631-1.

Change the paragraph under table 1 to:

> The frequency-weighted acceleration shall be integrated to a root-mean-square value over the duration of the measurement using linear averaging (see 3.3.1). The weighted root-mean-square acceleration may be calculated from acceleration spectra (see 4.3.2). The weighted acceleration may also be integrated to a running root-mean-square acceleration (see 3.3.3), vibration dose value (see 3.3.4), or motion sickness dose value (see 3.3.5). When quoting the weighted acceleration, the frequency weighting and the averaging method, including the appropriate integration time or time constant, shall be indicated.

Change NOTE to NOTE 1; add note 2:

> NOTE 2 For the evaluation of comfort in some environments (e.g. rail vehicles), a frequency weighting designated W_b may be applied in vertical direction (z). This weighting curve deviates from the W_k weighting (see annex B) and is defined in BS 6841:1987.

3.3 Equivalent continuous vibration value and level

Replace the whole clause by the following.

3.3 Root-mean-square and fourth-power values

3.3.1 weighted root-mean-square acceleration value

The weighted r.m.s. acceleration a_w, in metres per second squared or radians per second squared, is defined by the expression:

$$a_w = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)\,\mathrm{d}t} \qquad (1)$$

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.

3.3.2 weighted root-mean-square acceleration level

The weighted r.m.s. acceleration level expressed in decibels, is defined by

$$L_{\mathrm{a,w}} = 10 \cdot \lg(a_{\mathrm{w}}/a_0)^2 \ \mathrm{dB} \tag{2}$$

where

a_{w} is defined in 3.3.1;

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

3.3.3 weighted running root-mean-square acceleration value

The weighted running r.m.s. acceleration $a_{\mathrm{w}}(t_0)$, in metres per second squared, at the instantaneous observation time t_0 is defined by the expression:

$$a_{\mathrm{w}}(t_0) = \sqrt{\frac{1}{\tau}\int_{t_0-\tau}^{t_0} a_{\mathrm{w}}^2(t)\,\mathrm{d}t} \tag{3}$$

where

$a_{\mathrm{w}}(t)$ is the weighted instantaneous acceleration magnitude, in m/s^2;

τ is the integration time of the measurement, in seconds, preferably 1 s;

t is the time (integration variable).

Exponential averaging may be used for the running r.m.s. method, as an approximation of the linear averaging. The exponential averaging is defined as follows (see also annex D):

$$a_{\mathrm{w}}(t_0) = \sqrt{\frac{1}{\tau}\int_{-\infty}^{t_0} a_{\mathrm{w}}^2(t)\exp\left(\frac{t-t_0}{\tau}\right)\mathrm{d}t} \tag{4}$$

where

$a_{\mathrm{w}}(t)$ is the weighted instantaneous acceleration magnitude, in m/s^2;

τ is the time constant of the measurement, in seconds, preferably 1 s;

t is the time (integration variable).

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

The maximum of the running r.m.s. value is denoted MTVV (maximum transient vibration value).

NOTE In this International Standard there is no test procedure or tolerances defined for instrumentation to be used for the measurement of MTVV.

3.3.4 fourth-power vibration dose value (VDV)

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

$$\mathrm{VDV} = \sqrt[4]{\int_0^T a_{\mathrm{w}}^4(t)\,\mathrm{d}t} \tag{5}$$

where T is the duration of the measurement, in seconds.

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

NOTE In this International Standard there is no test procedure or tolerances defined for instrumentation to be used for the measurement of VDV.

3.3.5 motion sickness dose value (MSDV)

The integral of the squared weighted instantaneous acceleration $a_{\mathrm{w}}(t)$, in m/s^{1,5}, as defined by the expression:

$$\mathrm{MSDV} = \sqrt{\int_0^T a_{\mathrm{w}}^2(t)\,\mathrm{d}t} \tag{6}$$

where T is the duration of the measurement, in seconds.

The motion sickness dose value may be obtained from the weighted r.m.s. acceleration through multiplication by $\sqrt{T}$.

NOTE In this International Standard there is no test procedure or tolerances defined for instrumentation to be used for the measurement of MSDV.

3.4 crest factor

Replace definition by:

The ratio of the peak signal value evaluated over the duration of measurement to the r.m.s. value over the same time interval. The peak value is the largest deviation from the arithmetic mean of the frequency-weighted acceleration signal.

Delete NOTE.

3.8 reference calibration frequency

Replace table 2 by the following table:

Table 2 — Preferred reference calibration frequencies

Characteristics of vibration	Reference calibration frequency		Weighting	
	ω s^{-1}	f Hz	**factor**	dB
Principal whole-body:				
Whole-body, vertical, W_k	50	7,958	1,037 1	0,32
Whole-body, horizontal x and y, W_d	50	7,958	0,254 5	–11,89
Whole-body, motion sickness, W_f	2,5	0,398	0,388 8	–8,20
Whole-body, combined, W.B.combined	50	7,958	0,581 2	–4,71
Additional whole-body:				
Whole-body, seat back, horizontal x, W_c	50	7,958	0,893 3	–0,98
Whole-body, rotational, W_e	50	7,958	0,126 1	–17,98
Head of recumbent person, W_j	50	7,958	1,016	0,14
Hand-arm:				
All directions, W_h	500	79,58	0,202	–13,89

Page 3:

4 Characteristics

Last line: Replace IEC 225 by IEC 61260.

4.3 Weighting characteristics

Replace this subclause by the following.

4.3 Weighting characteristics

4.3.1 Frequency weighting of acceleration time history

For integration of the frequency weighted acceleration time history in order to assess human response to vibration, one or more of the following frequency weightings shall be applied. Frequency weighting characteristics are defined in annex B and shown in the tables indicated.

a) Principal weightings for whole-body vibration related to health, comfort and perception:

W_k for vertical z direction and for vertical recumbent direction (table 4);

W_d for horizontal x and y directions and for horizontal recumbent direction (table 5);

W.B.combined for vibrations in buildings (table 7).

b) Principal weighting for whole-body vibration related to motion sickness:

W_f for vertical z direction (table 6).

c) Additional weightings for whole-body vibration:

W_c for horizontal x direction of seat back vibration (table 8);

W_e for all axes of rotational seat vibration (table 9);

W_j for vertical x vibration under the head of a recumbent person (table 10).

d) Weighting related to hand-arm vibration:

W_h for all directions of hand-arm vibration (table 11).

Figures C.1 to C.8 in annex C illustrate the frequency weighting curves. Here, as well as in tables 4 to 11, the band limiting is included.

The frequency weightings may be realized by either analog filters or by digital methods applied in frequency or time domain. They are defined in a mathematical form familiar to filter designers in annex B. Equations for the frequency band limitation are expressed separately to enable a two-step filtering procedure.

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 of an octave outside the nominal frequency range of the relevant band.

Band limiting filters are high-pass at 0,4 Hz and low-pass at 100 Hz for weightings W_c, W_d, W_e, W_j and W_k, whereas the frequency weighting W_f has a high-pass filter at 0,08 Hz and a low-pass filter at 0,63 Hz. The W.B.combined weighting has a high-pass filter at 0,8 Hz and a low-pass filter at 100 Hz. For hand-arm filters, the high-pass and low-pass limits are 6,3 Hz and 1 250 Hz respectively.

Other optional weighting characteristics may be included.

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

Weighting and amplifier circuits shall satisfy the requirements of 5.1. When the flat response is provided, the manufacturer shall specify its frequency range and tolerances. The tolerances shall not be greater than those for the frequency-weighting characteristics (tables 4 to 11).

4.3.2 Frequency weighting of acceleration spectra

The acceleration may be analysed as either constant bandwidth or proportional bandwidth spectra (e.g. as one-third-octave bands or narrower) of the unweighted acceleration. Any form of frequency analysis, analog or digital, direct one-third-octave band or summation of narrow band data may be used.

In the case of one-third-octave bands, the centre frequencies shall be as stated in tables 4 to 11. In the case of constant bandwidth analysis, the frequency resolution (i.e. the interval between adjacent spectral lines) should be no larger than the bandwidth of the narrowest one-third-octave band within the nominal frequency range of the appropriate frequency weighting.

The frequency weighted r.m.s. acceleration shall be determined by frequency-weighting and appropriate summation of squared narrow band or one-third-octave band data. The overall weighted r.m.s. acceleration in m/s^2 or rad/s^2 shall be determined in accordance with the following equation:

$$a_\mathrm{w} = \sqrt{\sum_i (W_i a_i)^2} \qquad (7)$$

where

a_w is the weighted r.m.s. acceleration, in metres per second squared or radians per second squared;

W_i is the weighting factor for the i^th frequency band or spectral line;

a_i is the r.m.s. acceleration in the i^th frequency band or spectral line, over the duration of the measurement.

For narrow band r.m.s. data, weighting factors W_i may be obtained for each spectral line using the equations in annex B.

In the case of one-third-octave-band analysis, the filter characteristics shall be consistent with the one-third-octave-band filter specifications in IEC 61260.

If the acceleration spectrum is estimated from line spectra (i.e. FFTs), an appropriate method should be used to smooth the spectral estimate (e.g. subdivision of the acceleration record into overlapping segments and use of a tapering window to suppress side-lobe leakage).

In the case of narrow-band analysis of random vibration, the i^{th} squared acceleration $a_i{}^2$ in m^2/s^4 shall be obtained from power spectral density (PSD) data PSD_i through multiplication by the frequency resolution Δf:

$$a_i^2 = \text{PSD}_i \cdot \Delta f \qquad (8)$$

For narrow band (FFT) analysis consideration shall be given to ensure that the frequency resolution, windowing function, averaging, overlapping and other parameters are adequate.

For the application of equation (7) to one-third-octave data for whole-body vibration, weighting factors found in tables 3 and 4 of ISO 2631-1:1997 shall be applied. These are based on nominal mid-frequencies.

4.3.3 Integration in the time domain

Vibration-measuring instrumentation for human response shall, in the time domain, at least provide a linear integrated root-mean-square value of the frequency-weighted acceleration signal over a selectable time period (including 60 s and longer periods). The integration time shall be indicated by the instrumentation.

An instrument providing exponential averaging shall include a time constant of 1 s. If additional time constants are provided, these should preferably be 1/8 s or 8 s. The time constant used shall be indicated by the instrument.

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

The averaging method, linear or exponential, shall be indicated.

For the purpose of measuring the maximum transient vibration value (MTVV) (running r.m.s. acceleration), the instrumentation shall in addition provide a continuous or continuously sampled measurement of the short-time linear or exponentially integrated r.m.s. value. The selection of integration time (time constant) shall include 1 s. The SLOW characteristics defined for sound level meters in IEC 60651 may be used. The increment of a sampled observation time t_0 shall be smaller than the integration time. The maximum transient vibration value (MTVV) of the acceleration shall be indicated. The integration time used shall be indicated by the instrumentation.

NOTE 1 Results obtained using different time constants, τ, should not be compared.

For the purpose of measuring the fourth-power vibration dose (VDV), the instrumentation shall in addition to the integrated r.m.s. acceleration provide a fourth-power dose value according to equation (5). The measurement may be interrupted and continued. The total integration time used shall be indicated by the instrumentation.

For the purpose of measuring the motion sickness dose value (MSDV), the instrumentation must be capable of providing an accurately integrated value of the squared low frequency acceleration using a long integration time (perhaps several hours). The total integration time used shall be indicated by the instrumentation.

The crest factor should be used to indicate if the basic integrated r.m.s. acceleration is suitable for describing the severity of the vibration or if the additional integration methods above should be applied as well. For this purpose the instrumentation may be equipped with a facility to read out the peak value of the frequency-weighted instantaneous acceleration.

NOTE 2 The integration times specified should not be taken to be necessarily representative of an integration time of the human body.

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5.1 General

Replace the complete subclause by the following.

The complete instrumentation chain (comprising the transducer, amplifier, weighting network and detector-indicator) for measurements according to ISO 5349 (hand-arm) or ISO 2631-2 (whole-body combined) shall have either or both of the characteristics and tolerances given in tables 7 and 11.

The characteristics and tolerances of instrumentation used for measurement according to ISO 2631-1:1997 and given in tables 4, 5, 6, 8, 9 and 10 apply only to the combined frequency weighting and band-limiting.

Graphs and analytical expressions for each of the tables are given in annex B and annex C respectively.

Provisions for external filter connection may be included.

Pages 5 to 12:

Replace tables 4 to 8 by the following tables 4 to 11 and accordingly renumber tables 9 to 12 as tables 12 to 15.

Table 4 — Frequency weighting W_k for vertical whole body vibration (z-axis)
Seated, standing or recumbent person — Based on ISO 2631-1

x	**Frequency**, Hz		**Band-limit factor**	**Band limit** dB	**Weighting factor**	**Weighting** dB	W_k **factor**	W_k dB	**Tolerance** %	**Tolerance** dB
	Nominal	**True**								
–10	0,1	0,100 0	0,062 4	–24,10	0,500	–6,01	0,031 2	–30,11	+26	+2
–9	0,125	0,125 9	0,098 6	–20,12	0,500	–6,02	0,049 3	–26,14	+26	+2
–8	0,16	0,158 5	0,155	–16,19	0,500	–6,02	0,077 6	–22,21	+26	+2
–7	0,2	0,199 5	0,241	–12,34	0,500	–6,02	0,121	–18,37	+26	+2
–6	0,25	0,251 2	0,367	–8,71	0,499	–6,03	0,183	–14,74	$^{+26}_{-21}$	±2
–5	0,315	0,316 2	0,530	–5,51	0,499	–6,04	0,264	–11,55	$^{+26}_{-21}$	±2
–4	0,4	0,398 1	0,704	–3,05	0,498	–6,06	0,350	–9,11	$^{+12}_{-11}$	±1
–3	0,5	0,501 2	0,843	–1,48	0,497	–6,08	0,419	–7,56	$^{+12}_{-11}$	±1
–2	0,63	0,631 0	0,928	–0,65	0,495	–6,12	0,459	–6,77	$^{+12}_{-11}$	±1
–1	0,8	0,794 3	0,969	–0,27	0,492	–6,17	0,477	–6,44	$^{+12}_{-11}$	±1
0	1	1,000	0,987	–0,11	0,489	–6,22	0,482	–6,33	$^{+12}_{-11}$	±1
1	1,25	1,259	0,995	–0,04	0,487	–6,25	0,485	–6,29	$^{+12}_{-11}$	±1
2	1,6	1,585	0,998	–0,02	0,494	–6,12	0,493	–6,13	$^{+12}_{-11}$	±1
3	2	1,995	0,999	–0,01	0,531	–5,50	0,531	–5,50	$^{+12}_{-11}$	±1
4	2,5	2,512	1,000	0,00	0,634	–3,96	0,633	–3,97	$^{+12}_{-11}$	±1
5	3,15	3,162	1,000	0,00	0,807	–1,86	0,807	–1,86	$^{+12}_{-11}$	±1
6	4	3,981	1,000	0,00	0,965	–0,31	0,965	–0,31	$^{+12}_{-11}$	±1
7	5	5,012	1,000	0,00	1,039	0,33	1,039	0,33	$^{+12}_{-11}$	±1
8	6,3	6,310	1,000	0,00	1,054	0,46	1,054	0,46	$^{+12}_{-11}$	±1
9	8	7,943	1,000	0,00	1,037	0,32	1,037	0,32	0	0
10	10	10,00	1,000	0,00	0,988	–0,10	0,988	–0,10	$^{+12}_{-11}$	±1
11	12,5	12,59	1,000	0,00	0,899	–0,92	0,899	–0,93	$^{+12}_{-11}$	±1
12	16	15,85	1,000	0,00	0,775	–2,22	0,774	–2,22	$^{+12}_{-11}$	±1
13	20	19,95	0,999	–0,01	0,638	–3,91	0,637	–3,91	$^{+12}_{-11}$	±1
14	25	25,12	0,998	–0,02	0,511	–5,83	0,510	–5,84	$^{+12}_{-11}$	±1
15	31,5	31,62	0,995	–0,04	0,405	–7,85	0,403	–7,89	$^{+12}_{-11}$	±1
16	40	39,81	0,988	–0,11	0,320	–9,90	0,316	–10,01	$^{+12}_{-11}$	±1
17	50	50,12	0,970	–0,27	0,253	–11,95	0,245	–12,21	$^{+12}_{-11}$	±1
18	63	63,10	0,929	–0,64	0,200	–13,98	0,186	–14,62	$^{+12}_{-11}$	±1
19	80	79,43	0,846	–1,46	0,158	–16,01	0,134	–17,47	$^{+12}_{-11}$	±1
20	100	100,0	0,707	–3,01	0,125	–18,03	0,088 7	–21,04	$^{+12}_{-11}$	±1
21	125	125,9	0,534	–5,46	0,100	–20,04	0,053 1	–25,50	$^{+26}_{-21}$	±2
22	160	158,5	0,370	–8,64	0,079 0	–22,05	0,029 2	–30,69	$^{+26}_{-21}$	±2
23	200	199,5	0,244	–12,27	0,062 7	–24,05	0,015 3	–36,32	+26	+2
24	250	251,2	0,157	–16,11	0,049 8	–26,06	0,007 79	–42,16	+26	+2
25	315	316,2	0,100	–20,04	0,039 5	–28,06	0,003 93	–48,10	+26	+2
26	400	398,1	0,063 0	–24,02	0,031 4	–30,06	0,001 98	–54,08	+26	+2

NOTE x is the frequency band number according to IEC 61260:1995.
The table is based on true frequencies (exact values as defined in IEC 61260:1995).
Tolerance applies to the combination W_k of band-limiting and frequency weighting.