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Human response to vibration — Measuring instrumentation —

Part 2: Personal vibration exposure meters

Réponse des individus aux vibrations — Appareillage de mesure —

Partie 2: Instruments de mesure de l'exposition des personnes aux vibrations

Reference number
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Contents

Page

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Foreword

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This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 231, *Mechanical vibration and shock,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 8041 series can be found on the ISO website.

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Introduction

ISO 8041-1 specifies instruments for measuring human exposure to vibration. These instruments are used for temporary, short time measurements or controlled measurements.

This document specifies personal vibration exposure meters (abbreviated to PVEM) for measuring human exposure to vibration over long time periods, e.g. a whole working shift.

It is not necessary for PVEM to fulfil all of the specifications given in ISO 8041-1. On the other hand, it is necessary for them to fulfil other requirements which allow non-controlled measurements or stand-alone measurements over longer time periods. In combination with alarm functions, PVEM can make it possible to alert the user before vibration exposure reaches certain values (action value, limit value). For this reason, it is necessary to distinguish PVEM from the instrumentation specified in ISO 8041-1.

Whilst some potential applications and artefacts are covered in the informative annexes, this standard is an instrument standard and does not cover all potential applications of the PVEM. The reader should refer to measurement standards and guidance for further information.

Annex A describes the treatment of transient acceleration artefacts, Annexes B and C describe possible extension features with additional information for the measurement procedure.

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Human response to vibration — Measuring instrumentation —

Part 2:
Personal vibration exposure meters

1 Scope

This document specifies minimum requirements for personal vibration exposure meters (PVEM).

This document is applicable to instruments designed for measurements of whole-body vibration in the context of industrial hygiene applications (according to ISO 2631-1, ISO 2631-2 and ISO 2631-4) and/or hand-arm vibration (according to ISO 5349-1) together with the associated exposure times.

This document provides specified design goals and permitted tolerances that define the minimum performance capabilities and functional requirements of instruments designed to measure personal daily vibration exposure.

This document does not apply to instruments designed to measure or log exposure times without also performing vibration measurement. Instrumentation of this type is described in ISO/TR 19664.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

ISO 2631-1, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements*

ISO 2631-2, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 2: Vibration in buildings (1 Hz to 80 Hz)*

ISO 2631-4, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems*

ISO 5347 (all parts), *Methods for the calibration of vibration and shock pick-ups*

ISO 5349-1, *Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 1: General requirements*

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

ISO 8041-1:2017, *Human response to vibration — Measuring instrumentation — Part 1: General purpose vibration meters*

ISO 10326-1, *Mechanical vibration — Laboratory method for evaluating vehicle seat vibration — Part 1: Basic requirements*

ISO 15230-1, *Mechanical vibration and shock — Coupling forces at the man-machine interface for hand-transmitted vibration*

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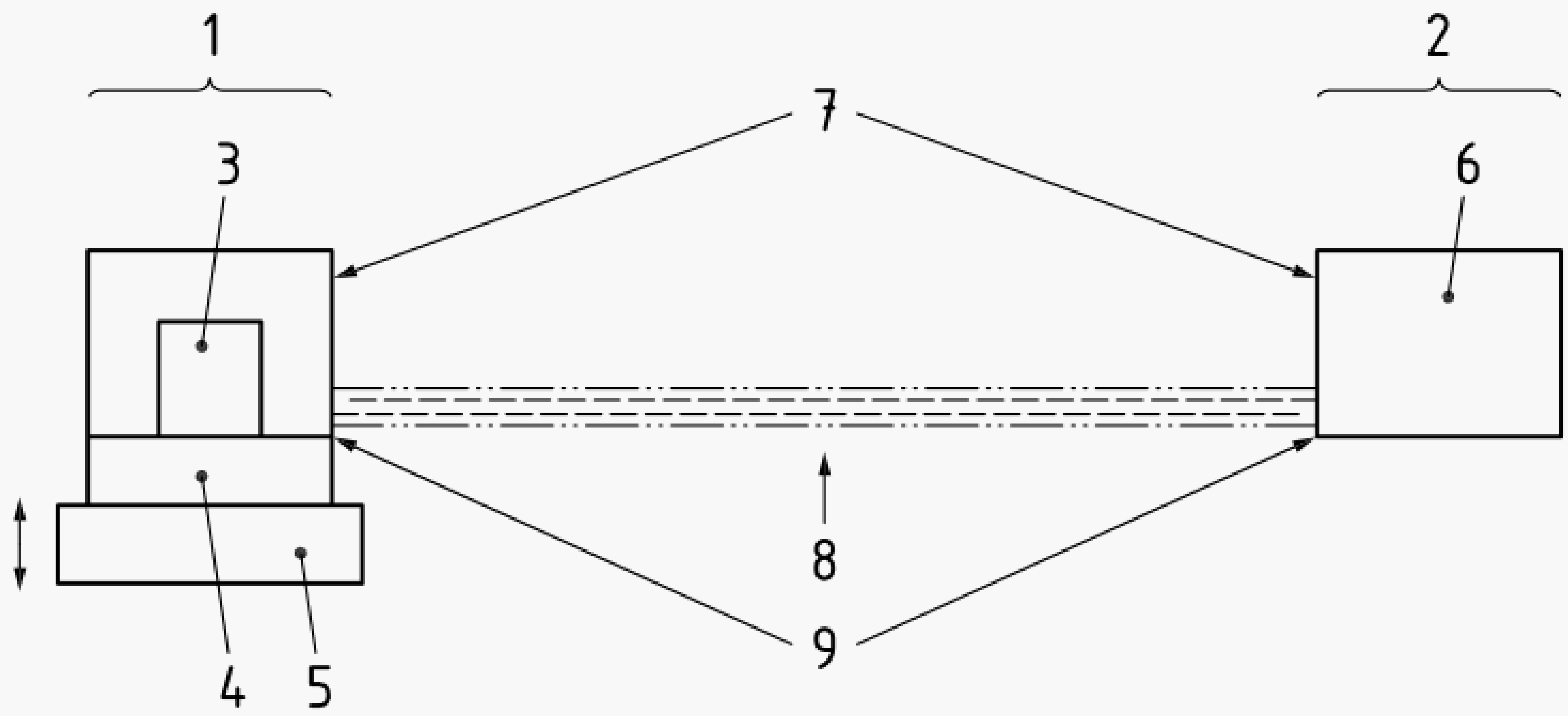

Key

1 part A
2 part B
3 transducer
4 coupling
5 vibrating surface
6 display and control
7 logging, signal processing
8 fixed or temporary wired or wireless interface
9 operator detection system (ODS)

Figure 1 — Principal components of a PVEM

3.2
permanent measurement system
system which is permanently incorporated into or fitted onto a machine

Note 1 to entry: A permanent measurement system is not designed to be routinely transferred to other vibrating machinery.

3.3
non-permanent measurement system
system which is designed to be used on several machines or other vibrating objects

Note 1 to entry: A non-permanent measurement system is capable of routinely being transferred from one vibrating object or machine to another.

3.4
user
person authorized to operate a *PVEM* (3.1)

3.5
operator
worker
person who performs a work task at a workplace

3.6
logging
storing measured acceleration values at regular time intervals

3.7
logging step
time interval between the start of two consecutive *logging* (3.6) periods

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3.8
measurement period
duration of all measurements, representing the *worker's* (3.5) exposure time

Note 1 to entry: The measurement period usually comprises many *logging steps* (3.7).

3.9
transient acceleration artefact
event or effect that can alter the computation of *workers'* (3.5) daily exposure to vibration

Note 1 to entry: For a *PVEM* (3.1), it is essential to log sufficient information to identify transient acceleration artefacts for the purpose to treat them in real time or in the post-processing.

4 Reference environmental conditions

Reference environmental conditions for specifying the performance of a personal vibration exposure meter are the following:

— air temperature: 23 °C;

— relative humidity: 50 %.

5 Performance specifications

5.1 General characteristics

5.1.1 Common characteristics

A personal vibration exposure meter (PVEM) is a vibration measurement system meeting the relevant requirements of ISO 8041-1 with the additional capability to monitor personal exposures up to a full working day.

Since personal vibration exposure meters are instruments capable of measuring and computing daily vibration exposures they are simple to use and implement (internal complexity hidden from the user) and automatic (i.e. they do not require manual post-processing or computations), while displaying accurate and reliable results. Hence, as compared to general-purpose vibration meters, PVEM shall run algorithms that replace as much as possible any required manual signal post-processing.

Particularly, one design goal is to identify measurement events or periods that might need to be rejected and that could be automatically discarded from the vibration exposure computation using artefact rejection algorithms. Those automatic artefacts rejection algorithms are an additional feature of PVEM as compared to general-purpose vibration meters. In operation PVEMs are typically left unattended.

5.19 to 5.24 give additional recommendations and specifications for PVEM.

The PVEM may consist of separate parts (see parts A and B in Figure 1). Part B of the PVEM provides the means to present the results of measurements. The presentation of results may be in any suitable form, e.g. continuous “live” display or upload of measured values to a dedicated displaying unit or a computer at the end of the measurement period. Part B is an inherent part of the PVEM and compulsory for a pattern evaluation and periodic verification of the PVEM. However it needs not to be used with part A for the period of exposure measurement.

In addition to the relevant requirements of ISO 8041-1, a PVEM shall

— derive vibration exposure by measuring vibration magnitudes and directly related exposure times,

— measure vibration in three directions (x, y, z) simultaneously,

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— provide capability for measurement over the period of a working day (at least 12 h) without intervention by the user,

— include a real-time clock,

— continuously log vibration data versus time over the full measurement period at suitable programmable intervals which are no greater than 1 s,

NOTE Suitable logging steps can be as defined in ISO 2631-4 or selected by the user. The manufacturer can provide a choice of logging periods according to the measurement type.

— store logged vibration exposure data in a non-volatile memory, such that the data are not compromised if the power supply is interrupted (e.g. if the battery is low or being replaced),

— output information on logged vibration magnitudes, corresponding real time, and overall daily vibration exposure and daily exposure time, and

— provide information that will assist the user to exclude transient acceleration artefacts from exposure measurements (see Annex A).

The facility for reading measurement data from the instrument may be a direct display on the instrument or a remote display, or both.

Where the PVEM provides alarms for exposure exceedances, then the manufacturer shall provide information on the conditions for the alarm trigger points and on any capability to adjust the exposure trigger levels.

The reference vibration signal values and reference frequencies are given in Table 1.

Not all of the frequency weightings given in Table 1 need to be implemented in a PVEM, and further frequency weightings (see ISO/TR 18570) may also be implemented. The manufacturer shall state which frequency weightings are implemented.

Table 1 — Reference vibration values and frequencies

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

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5.1.2 Special characteristics for whole-body vibration measurement

For instruments designed for whole-body vibration, the PVEM shall

— measure vibration at the interface between the machine and the operator's body (in accordance with ISO 2631-1),

— be capable of responding to vibration peak values up to 50 m/s^2,

NOTE In special applications vibration peak values up to 200 m/s^2 have been observed.

— measure exposure characteristics based on A(8) exposures,

— optionally, measure exposure characteristics based on vibration dose value (VDV),

— optionally, measure exposure characteristics based on maximum transient vibration value (MTVV),

— optionally, measure exposure characteristics based on motion sickness dose value (MSDV),

— allow all part A components (see Figure 1) to be fitted unobtrusively to either the machine seat or the machine operator,

— (for non-permanent and optionally for permanent measurement systems) incorporate the part A component of the instrument into a seat pad meeting the requirements of ISO 10326-1, and

— (for permanent measurement systems not using a seat pad) incorporate the part A component of the PVEM into a seat structure in a way that does not adversely impact the seat suspension system or comfort of the driver but provides measurements equivalent to that required by ISO 2631-1 for health effects.

The directions of the three orthogonal axes shall be marked on the transducer.

5.1.3 Special characteristics for hand-arm vibration measurement

For instruments designed for hand-arm vibration, the PVEM shall

— measure vibration at the interface between the machine and the operator's hand (in accordance with ISO 5349-1). The directions of the three orthogonal axes shall be marked on the transducer.

— define the range of application of the PVEM based on the maximum peak vibration capability of the instrument. In any case, as a minimum, the transducer shall be capable of responding to peak accelerations up to 2 000 m/s^2.

NOTE Higher peak acceleration capability is needed for measurements on impactive machines (e.g. up to 30 000 m/s^2).

— allow all part A components (see Figure 1) to be fitted unobtrusively to either the machine operator or the vibrating machine (see ISO 5349-2).

The part A component of the instrument shall conform to the requirements of ISO 5349-1 and take account of the guidance given in ISO 5349-2. The part A component of the instrument may be incorporated into or fitted to a machine or power tool. If the part A component is incorporated into the device an operator identification system can be necessary.

If the PVEM is designed to provide evaluation of coupling forces, it shall conform to the applicable requirements of ISO 15230-1.

5.2 Display

Displaying of the vibration magnitude and other results measured by the PVEM should be provided by part B of the instrument at least for testing purpose (see Figure 1).

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For type approval and periodic verification, the instrument shall display the frequency-weighted acceleration values.

The display device(s) specified in the instrument documentation shall permit displayed measurement values with a resolution of not more than 1 % of the indicated value.

Within the prevailing environmental conditions, the time interval required for stabilizing and being ready to use shall be documented.

For instruments that can display more than one measurement quantity, a means shall be provided to ascertain clearly the measurement quantity that is being displayed, preferably indicated by standard abbreviations or letter symbols.

The quantities that can be displayed by the PVEM shall be described in the instrument documentation, along with a description of the corresponding indications on each display device.

When results of a measurement are provided at a digital output, the instrument documentation shall describe the method for transferring or downloading the digital data to an external data storage or display device, e.g. a computer. The instrument documentation shall identify the software as well as the hardware for the interface. Internationally standardized interface bus compatibility is recommended.

For instruments with digital display devices updated at periodic intervals, the indication at each display update shall be the value of the user-selected quantity at the time of the display update. Other modes of indication at the time of the display update may be identified in the instrument documentation and, if so, the operation of such modes shall be explained in the instrument documentation. The instrument documentation shall state which modes conform to the specifications of this document and which do not conform.

5.3 Electrical output

No AC electrical output for PVEM is required.

5.4 Vibration sensitivity

The instrument documentation shall specify at least one model of field vibration calibrator as a means to check and maintain the mechanical sensitivity of the PVEM. The field vibration calibrator shall conform to the specifications given in ISO 8041-1:2017, Annex A. The manufacturer shall describe the attachments and jigs used with the vibration calibrator in the instruction manual.

The instrument documentation for the vibration instrument shall describe the procedure for adjusting the indicated vibration to conform to the specifications in this document by application of the specified field vibration calibrator. The adjustment shall apply to the models of vibration transducers recommended in the instrument documentation for use with the PVEM. The adjustment shall also apply to any cables, connectors and other accessories provided by the manufacturer of the instrument for connecting a vibration transducer to the instrument.

5.5 Accuracy of indication at reference frequency under reference conditions

The requirements for tolerance of the displayed results are given in Table 2. The tolerance of indication is specified at the appropriate reference frequency and reference vibration value specified in Table 1 with the instrument switched to the reference measurement range, with sinusoidal mechanical vibration applied to the base of the vibration transducer or specified mounting device. The requirements apply to all frequency weightings specified in this document and after applying adjustments described in 5.4 and after the specified stabilization time interval has elapsed.

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Table 2 — Tolerances of indication at reference frequency and reference vibration value

Parameter	Tolerance
Tolerance of indication at the reference frequency under reference environmental conditions	±4 % for hand-transmitted and whole-body vibration
	±5 % for low-frequency whole-body vibration
The difference between the indicated value of any frequency-weighted measurement quantity and the indicated value of the corresponding band-limiting measurement multiplied by the appropriate weighting factor (for a steady sinusoidal input vibration signal at the reference frequency and reference vibration value) (See also Table 11)	±3 %

5.6 Frequency weightings and frequency responses

5.6.1 Parameters

A PVEM shall have one or more of the frequency weightings listed in Table 1, including the appropriate band-limiting weightings. The frequency weightings are defined by Formulae (1) to (5) and the parameters given in Table 3.

Table 3 — Parameters and transfer functions of the frequency weightings

Weighting	Band-limiting				a-v transition			Upward step				Gain
	f_1 Hz	Q_1	f_2 Hz	Q_2	f_3 Hz	f_4 Hz	Q_4	f_5 Hz	Q_5	f_6 Hz	Q_6	K
W_b	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	16	16	0,55	2,5	0,9	4	0,95	1,024
W_c	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	8	8	0,63	∞	1	∞	1	1
W_d	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	2	2	0,63	∞	1	∞	1	1
W_e	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	1	1	0,63	∞	1	∞	1	1
W_f	0,08	$1/\sqrt{2}$	0,63	$1/\sqrt{2}$	∞	0,25	0,86	0,062 5	0,80	0,10	0,80	1
W_h	$10^{8/10}$	$1/\sqrt{2}$	$10^{31/10}$	$1/\sqrt{2}$	100/(2π)	100/(2π)	0,64	∞	1	∞	1	1
W_j	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	∞	∞	1	3,75	0,91	5,32	0,91	1
W_k	0,4	$1/\sqrt{2}$	100	$1/\sqrt{2}$	12,5	12,5	0,63	2,37	0,91	3,35	0,91	1
W_m	$10^{-0,1}$	$1/\sqrt{2}$	100	$1/\sqrt{2}$	1/(0,028 × 2 π)	1/(0,028 × 2 π)	0,5	∞	1	∞	1	1

NOTE 1 For weighting W_b, ISO 2631-4:2001, Table A.1, rounds the value of parameter Q_1 to two decimal places. The parameter specified here is the exact value.

NOTE 2 For weighting W_h, ISO 5349-1:2001, Table A.1, rounds the values of parameters f_1, f_2, f_3 and f_4 to five significant figures and parameter Q_1 to two decimal places. The parameters specified here are the exact values.

The angular frequencies ω_1, ..., ω_6 (given by $\omega_i = 2\pi f_i$ where f_i are the frequencies f_1, ..., f_6 in Table 3) and the resonant quality factors Q_1, Q_2, Q_4, Q_5 and Q_6 are parameters of the transfer functions in Formulae (1) to (5) which determine the overall vibration acceleration frequency weightings. The overall frequency weighting function is the product of band-limiting, a-v transition and upward-step filters.

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5.6.2 Band-limiting filter

The band-limiting element is a combination of high- and low-pass second-order Butterworth filter characteristics. These components are defined as shown by Formulae (1) and (2):

a) High pass

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

b) Low pass

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

The product $H_{\mathrm{h}}(s) \cdot H_{\mathrm{l}}(s)$ represents the band-limiting transfer function.

5.6.3 a-v transition filter

The a-v transition filter is proportional to acceleration at lower frequencies and to velocity at higher frequencies, as shown by Formula (3):

$$H_{\mathrm{t}}(s)=\frac{\left(1+\frac{s}{\omega_3}\right)K}{1+\frac{s}{Q_4 \omega_4}+\left(\frac{s}{\omega_4}\right)^2} \tag{3}$$

NOTE $H_{\mathrm{t}}(s) = 1$ when both f_3 and f_4 (ω_3 and ω_4) equal infinity.

5.6.4 Upward-step filter

The upward-step filter has a steepness of approximately 6 dB per octave and is proportional to jerk, as shown by Formula (4):

$$H_{\mathrm{s}}(s)=\frac{1+\frac{s}{Q_5 \omega_5}+\left(\frac{s}{\omega_5}\right)^2}{1+\frac{s}{Q_6 \omega_6}+\left(\frac{s}{\omega_6}\right)^2}\left(\frac{\omega_5}{\omega_6}\right)^2 \tag{4}$$

NOTE $H_{\mathrm{s}}(s) = 1$ when both f_5 and f_6 (ω_5 and ω_6) equal infinity.

5.6.5 Overall frequency weighting

The overall frequency weighting function for each weighting, W_x, is the product of band-limiting, a-v transition and upward-step filters, as shown by Formula (5):

$$H(s) = H_{\mathrm{h}}(s) \cdot H_{\mathrm{l}}(s) \cdot H_{\mathrm{t}}(s) \cdot H_{\mathrm{s}}(s) \tag{5}$$

The most common interpretation of these formulae is in the frequency domain, where they describe the modulus (magnitude) and phase of the frequency weightings as functions of the imaginary angular frequency $s = j2\pi f$.

NOTE 1 Sometimes the letter p is used instead of s.

NOTE 2 s can be interpreted as the variable of the Laplace transform.

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The tables and weighting curves given in ISO 8041-1:2017, Annex B, illustrate the magnitude and phase of the frequency weightings defined by Formulae (1) to (5) and Table 3, as functions of frequency, *f*.

If a PVEM provides one or more optional frequency responses, the instrument documentation shall state the design-goal frequency response and the tolerance limits that are maintained around the design goal(s). If an optional frequency response is specified in an International Standard, the design-goal frequency response shall be as specified in that International Standard.

The filters defined by Table 3 and Formulae (1) to (5) may be realized by combinations of simple analogue filters. ISO 8041-1:2017, Annex C, provides an example of how the frequency weightings can be realized digitally in the time and frequency domains.

5.6.6 Tolerances

The tolerances on the frequency weightings are given in Tables 4 and 5. The tolerance limits in Table 5 apply to the weightings, including the corresponding band-limiting weightings, on all measurement ranges. Tolerance limits include the applicable maximum expanded uncertainties of measurement.

The phase response of vibration instrumentation is critical to measured parameters not based on the RMS average value, e.g. peak, MTVV and VDV. The phase response is given by Formulae (1) to (5). However, the errors in measurement due to errors in the phase response are dependent on the rate of change in phase error with frequency, rather than the absolute phase error itself. For this reason, the phase response is assessed using the characteristic phase deviation, $\Delta\varphi_0$, as defined by Formula (6):

$$\Delta\varphi_0 = \left| \frac{f_n \Delta\varphi_{n+1} - f_{n+1} \Delta\varphi_n}{f_{n+1} - f_n} \right| \quad (6)$$

where

f_n is the centre frequency at one-third-octave band number *n*;

$\Delta\varphi_n$ is the phase error at frequency corresponding to one-third-octave band number *n*.

Table 4 — Transition frequencies for frequency weighting tolerances

Weighting	Tolerance transition frequencies Hz			
	f_{t1}	f_{t2}	f_{t3}	f_{t4}
W_b	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_c	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_d	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_e	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_f	$10^{-13/10}$ (0,05012)	$10^{-9/10}$ (0,1259)	$10^{-4/10}$ (0,3981)	$10^{0/10}$ (1)
W_h	$10^{6/10}$ (3,981)	$10^{10/10}$ (10)	$10^{29/10}$ (794,3)	$10^{33/10}$ (1995)
W_j	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_k	$10^{-6/10}$ (0,2512)	$10^{-2/10}$ (0,631)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)
W_m	$10^{-3/10}$ (0,5012)	$10^{1/10}$ (1,259)	$10^{18/10}$ (63,1)	$10^{22/10}$ (158,5)

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Table 5 — Tolerances on frequency weightings

Frequency, f	Magnitude tolerance	Characteristic phase deviation[a] $\Delta\varphi_0$
$f \leq f_{t1}$	+26 %, −100 %	±∞
$f_{t1} < f < f_{t2}$	+26 %, −21 %	±12°
$f_{t2} \leq f \leq f_{t3}$	+12 %, −11 %	±6°
$f_{t3} < f < f_{t4}$	+26 %, −21 %	±12°
$f_{t4} \leq f$	+26 %, −100 %	±∞

[a] Characteristic phase deviation tolerances only apply to instruments that provide measurement parameters that are not based on RMS values.

5.7 Amplitude linearity

Over the entire measurement range, the indicated signal value shall be a linear function of the mechanical vibration value at the vibration transducer. This design goal applies at any frequency within the frequency range of the instrument at any frequency weighting or frequency response provided. The linearity specifications apply to the whole instrument, including the transducer, and to all measured vibration parameters.

Over the full extent of all the measurement ranges, the linearity error shall not exceed 6 % of the input value. On the reference measurement range and at the reference frequency, the linear operating range shall be at least 70 dB.

NOTE For hand-arm vibration, a greater linearity range can be necessary for the measurement of highly impactive vibration signals.

The instrument documentation shall state the range of vibration values within which the linearity error does not exceed 6 % without indication of overload. This requirement applies for steady sinusoidal signals at any frequency in the nominal frequency range.

For the measurement range, the instrument documentation shall state the range of vibration values that can be measured without overload, i.e. the upper boundary of the linear operating ranges.

5.8 Instrument noise

For time-averaged frequency-weighted vibration, the instrument documentation shall state the typical indications that will be observed on the display device when the vibration transducer of the instrument is fitted to a non-vibrating object that does not add significantly to the indications. The indications shall correspond to the total inherent noise from the combination of the recommended vibration transducer(s) and the other components of the PVEM, at least for reference environmental conditions.

5.9 Signal-burst response

The specification of human-vibration instruments for the response to signal bursts is given in terms of the response to saw-tooth signals at the reference frequency.

The saw-tooth test signal is illustrated in Figure 2. The tests are carried out using saw-tooth burst with the characteristics given in Table 6. The responses given in Tables 7 to 9 are relative to a 1 m/s^2 amplitude signal and shall be multiplied by the amplitude of the actual test signal.

NOTE 1 The response to the saw-tooth signal burst is determined by digital simulation of the filter characteristics.

NOTE 2 The saw-tooth wave shape has been chosen to ensure that the signal burst contains combinations of frequencies with known phase relationships. The saw-tooth burst test therefore ensures that the relative phase response of the frequency weighting at different frequencies is tested.

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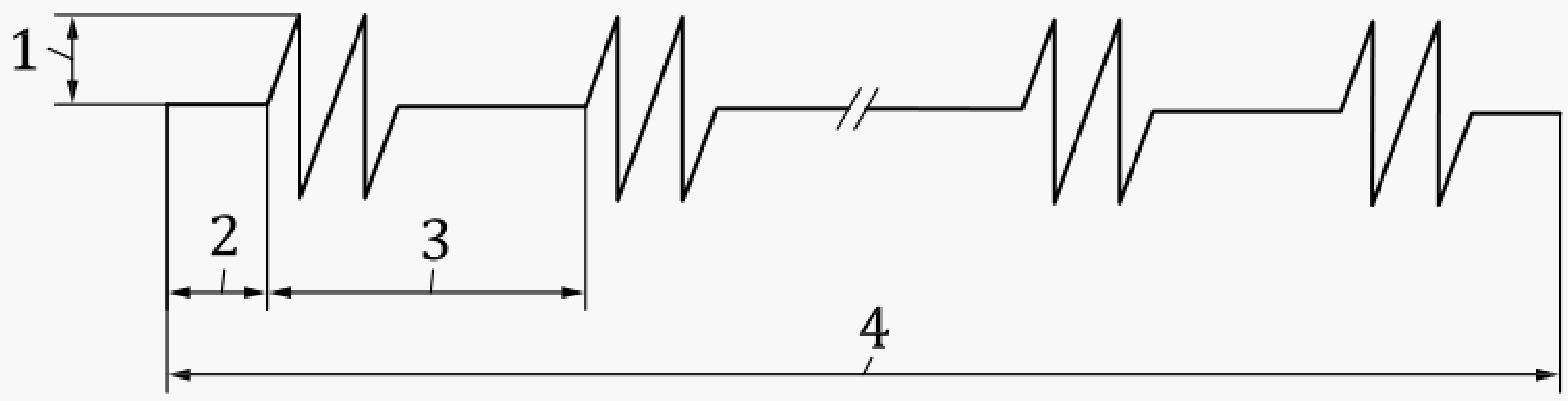

Key

1 amplitude
2 start time
3 repeat time
4 duration

Figure 2 — Theoretical saw-tooth burst test signal (2-cycle bursts illustrated)

Table 6 — Saw-tooth signal burst test signal characteristics

Application	Weighting	Angular frequency	Start time s	Number of cycles	Repeat time s	Duration s
Hand-arm	W_h	500 rad/s (79,58 Hz)	0,2		2	12
Whole-body	W_b, W_c, W_d, W_e, W_j, W_k, W_m	100 rad/s (15,915 Hz)	1	1, 2, 4, 8, 16	10	60
Low-frequency whole-body	W_f	2,5 rad/s (0,3979 Hz)	40		400	2 400

Table 7 — Saw-tooth signal burst response for hand-arm vibration measurements

Weighting	Number of saw-tooth cycles per burst	RMS value	Tolerance %
Band limiting	1	0,044 8	10
	2	0,063 3	10
	4	0,089 5	10
	8	0,127	10
	16	0,179	10
	Continuous	0,565	10
W_h	1	0,010 3	10
	2	0,013 3	10
	4	0,016 8	10
	8	0,022 4	10
	16	0,030 9	10
	Continuous	0,094 6	10

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

Weighting	Number of saw-tooth cycles per burst	RMS value	Tolerance %	VDV	Tolerance %	MTVV linear	Tolerance %	MTVV exponential	Tolerance %
Band limiting	1	0,043 3	10	0,498	12	0,137	10	0,135	10
	2	0,061 2	10	0,593	12	0,193	10	0,188	10
	4	0,086 5	10	0,705	12	0,274	10	0,258	10
	8	0,122	10	0,838	12	0,387	10	0,344	10
	16	0,173	10	0,996	12	0,547	10	0,437	10
	Continuous	0,546	10	1,77	12	0,547	10	0,549	10
W_b	1	0,031 4	10	0,342	12	0,099 1	10	0,096 8	10
	2	0,043 5	10	0,403	12	0,137	10	0,132	10
	4	0,061 4	10	0,482	12	0,194	10	0,182	10
	8	0,086 7	10	0,575	12	0,274	10	0,243	10
	16	0,123	10	0,685	12	0,387	10	0,309	10
	Continuous	0,387	10	1,22	12	0,388	10	0,388	10
W_c	1	0,022 2	10	0,244	12	0,070 3	10	0,068 4	10
	2	0,029 2	10	0,275	12	0,092 3	10	0,088 5	10
	4	0,039 7	10	0,318	12	0,126	10	0,117	10
	8	0,055	10	0,374	12	0,174	10	0,153	10
	16	0,077	10	0,445	12	0,243	10	0,192	10
	Continuous	0,24	10	0,788	12	0,243	10	0,242	10
W_d	1	0,006 69	10	0,077 9	12	0,021 2	10	0,019 7	10
	2	0,009 06	10	0,085 2	12	0,028 6	10	0,026 4	10
	4	0,011 6	10	0,092 3	12	0,036 6	10	0,033	10
	8	0,014 8	10	0,101	12	0,046 9	10	0,04	10
	16	0,019 7	10	0,115	12	0,061 1	10	0,048 1	10
	Continuous	0,059	10	0,197	12	0,061 1	10	0,059 4	10
W_e	1	0,003 42	10	0,040 9	12	0,010 8	10	0,009 92	10
	2	0,004 78	10	0,045 2	12	0,015 1	10	0,013 5	10
	4	0,006 37	10	0,049 3	12	0,020 1	10	0,017 6	10
	8	0,008 16	10	0,053 5	12	0,025 5	10	0,021 4	10
	16	0,010 2	10	0,059 2	12	0,031 1	10	0,024 4	10
	Continuous	0,029 5	10	0,098 7	12	0,031 1	10	0,029 7	10
W_j	1	0,043 5	10	0,517	12	0,138	10	0,135	10
	2	0,0616	10	0,609	12	0,195	10	0,189	10
	4	0,0874	10	0,723	12	0,277	10	0,261	10
	8	0,124	10	0,859	12	0,392	10	0,349	10
	16	0,175	10	1,02	12	0,554	10	0,443	10
	Continuous	0,554	10	1,81	12	0,555	10	0,557	10
W_k	1	0,0299	10	0,323	12	0,094 4	10	0,092 2	10
	2	0,0411	10	0,38	12	0,13	10	0,125	10
	4	0,0577	10	0,455	12	0,182	10	0,171	10
	8	0,0814	10	0,543	12	0,257	10	0,228	10
	16	0,115	10	0,648	12	0,363	10	0,289	10
	Continuous	0,362	10	1,15	12	0,364	10	0,363	10

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Table 8 *(continued)*

Weighting	Number of saw-tooth cycles per burst	RMS value	Tolerance %	VDV	Tolerance %	MTVV linear	Tolerance %	MTVV exponential	Tolerance %
W_m	1	0,0149	10	0,165	12	0,047 2	10	0,045 6	10
	2	0,0197	10	0,185	12	0,062 3	10	0,059 4	10
	4	0,0264	10	0,211	12	0,083 6	10	0,077 5	10
	8	0,0363	10	0,247	12	0,115	10	0,101	10
	16	0,0507	10	0,294	12	0,16	10	0,126	10
	Continuous	0,158	10	0,52	12	0,16	10	0,159	10

Table 9 — Saw-tooth signal burst response for low-frequency whole-body vibration measurements

Weighting	Number of saw-tooth cycles per burst	RMS value	Tolerance %	MSDV	Tolerance %
Band limiting	1	0,034 1	10	1,671	10
	2	0,048 7	10	2,386	10
	4	0,069	10	3,38	10
	8	0,098 2	10	4,811	10
	16	0,139	10	6,81	10
	Continuous	0,439	10	21,51	10
W_f	1	0,019 7	10	0,965 1	10
	2	0,023 6	10	1,156	10
	4	0,030 4	10	1,489	10
	8	0,041 6	10	2,038	10
	16	0,057 1	10	2,797	10
	Continuous	0,176	10	8,622	10

5.10 Overload indication

The PVEM shall have an overload indicator and shall be capable of detecting overloads at all critical points in the vibration signal path. Overloading the transducer shall be avoided by appropriate means (e.g. selection of suitable transducer for the intended measurement, electrical overload detector incorporated into the transducer, use of mechanical filter).

Overload shall be indicated before the tolerance limits for linearity or the signal-burst response tolerances are exceeded for increasing signal values above the specified upper boundary. This requirement applies for any frequency within the nominal frequency range.

The overload indicator shall latch on when an overload condition occurs. The latched condition shall remain on until the measurement results are cleared on the instrument. This requirement also applies to measurements of maximum vibration values, peak vibration values, or other quantities calculated during, or displayed after, the measurement duration. The overload conditions shall be logged for each logging step.

The instrument documentation shall describe the operation and interpretation of the overload indication and the method for clearing a latched indication.

NOTE It is useful for the instrument to be capable of indicating how long (in relation to the measurement duration) in each channel overload took place.

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5.11 Under-range indication

Not required for PVEM.

5.12 Time averaging

The instrument shall allow the measurement duration of the time-averaged weighted acceleration value to be selected or controlled by the user. A PVEM shall provide at least 12 h of exposure value calculation.

5.13 Running RMS acceleration

Not applicable for PVEM.

5.14 Clearance of data and instrument state (named reset)

For all frequency weightings provided, instruments intended for the measurement of time-averaged human vibration, maximum transient vibration value or vibration dose value shall contain a facility to stop the measurement, clear the data storage as required and reinstate a measurement. The instrument documentation shall state whether the reset facility clears the overload indication. The instrument documentation also shall describe the operation of the reset facility and state the nominal delay time between the operation of a manual or remote reset facility and the initiation of a measurement. Use of a reset facility shall not give rise to random indications on the display device(s).

5.15 Timing facilities

If an instrument displays the duration of the time elapsed since the start of integration then the following requirements apply.

The tolerance limit for the indicated elapsed time is 0,1 %. The resolution of the display of elapsed time shall not be coarser than 1 s.

The instrument documentation shall state the minimum and the maximum integration times for the measurement of time-averaged vibration values for any signal value within the range of a display device.

5.16 Electrical cross-talk

Electrical cross-talk is the response on any one channel (axis) to a signal on any of the other input channels. It shall be less than 0,5 % of the input signal magnitude.

This electrical cross-talk between measurement channels should be distinguished from transducer transverse sensitivity which typically is greater than 0,5 %, see ISO 8041-1:2017, Table E.1. The transverse sensitivity can become relevant especially with multi-axial transducers.

5.17 Vibration transducer characteristics

Vibration transducer characteristics shall be selected according to the measurement application, see ISO 8041-1:2017, Annex E, for additional guidance.

5.18 Power supply

For battery-powered instruments, an indication shall be provided to confirm that the power supply is sufficient to operate the instrument within the specifications of this document. A check of the power supply condition shall not disturb any measurements that are underway.

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When a vibration calibration signal is applied to the vibration transducer, the change in the indicated signal value shall not exceed 3 % when the supply voltage to operate the vibration instrument is reduced from the nominal value to the minimum voltage specified in the instrument documentation.

If internal batteries power the PVEM, the instrument documentation shall recommend acceptable battery types and state the corresponding continuous instrument operating time, under reference environmental conditions, to be expected when full-capacity batteries are installed.

For battery-powered instruments designed to be able to measure vibration values over durations that exceed the nominal battery life, the instrument documentation shall describe suitable means for operating the instrument from an external power supply, including specifications for the acceptable voltage range and ripple content (including high-frequency spikes) of the supply.

The PVEM internal battery shall warrant at least 12 h continuous operation time.

NOTE An indication whether a minimum of 90 % of battery capacity is available is helpful for the user.

5.19 Operator detection system

PVEM may provide an operator detection system (ODS) which recognizes the presence of an operator exposed to vibration.

The goal of using ODS is to avoid errors of the vibration exposure assessment by elimination of times with no vibration exposure.

Different operator detection systems are possible which might be based on various methods (contact force, optical, radio signal, etc.).

Information available from ODS shall be logged within one logging step and should be logged together with the measurement results.

Automatic operator identification is an optional feature of a PVEM, i.e. recognition which operator is using the machine.

The operation of the ODS should be described in the documentation.

5.20 Detection of transient acceleration artefacts

A PVEM should be able to detect transient acceleration artefacts and mark the measurement signal accordingly. The PVEM should be capable to calculate the time percentage of artefact occurrences during the measurement duration.

EXAMPLE Transient acceleration artefacts manifest themselves e.g. by a zero or faulty signal (loose transducer mounting, broken cable) or by peaks in the measurement signal (unoccupied seat hitting the end stop). However, since VDV emphasizes shocks, not all peaks are manifestations of transient acceleration artefact.

If an automatic algorithm for dealing with artefacts is provided, it is necessary to describe in the instrument documentation how transient acceleration artefacts are handled, as well as the way how periods with artefacts can be managed during post-processing. For optional testing purposes, the manufacturer shall state how artefact treatment takes place.

For examples of artefact identification, see Annex A.

5.21 Logging capabilities

Instruments meeting the requirements of this document are required to have logging capabilities. Additional information is provided on how instruments can use the logged data for post-processing, e.g. to identify transient acceleration artefacts in the measurement so that they can be excluded from vibration exposure values and the evaluation of accurate vibration exposure times.

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A PVEM shall have a non-volatile memory capable of logging all measured data over at least 12 h with logging steps not longer than 1 s. Logged data shall also contain real-time data stamps.

The content of the logged file shall be available for inspection and post-processing (e.g. artefact handling). The way of access to the logged data shall be described in the instrument documentation.

5.22 Contact force measurement

Coupling forces between the hand-arm system and hand-held or hand-guided machines are very important factors for the hand-transmitted vibration assessment. ISO 5349-1 notes that the coupling of the hand to the vibrating surface can affect considerably the vibration magnitudes measured.

NOTE See ISO 5349-1:2001, 4.3 and Introduction of ISO 5349-2:2001.

For more information on hand contact force measurement, see Annex B.

When measurement of the contact force is provided by the PVEM it should be logged together with the vibration measurements.

5.23 Warning indication

5.23.1 General

PVEM shall include the facility to automatically signal warnings in order to give the user the best support during the measurement. To help the user to be aware of the existing vibration situation and to give information on the status of the PVEM device, PVEM shall have certain warning indications (see 5.23.2) and can have additional warning indications (see 5.23.3). The warning thresholds shall be programmable. Warning indications may be switched off.

5.23.2 Mandatory warning indications

Certain system warnings are required to avoid wrong measurements. It is necessary to have indicators which indicate that the PVEM is not able or will soon not be able to fulfil the task.

Therefore, the following indicators shall be implemented:

a) information whether the PVEM is ready for use;

b) battery indicator;

c) overload indicator;

d) transducer communication failure.

The way to inform the user can be different. E.g. the following forms of alarm are possible:

— visual using e.g. LEDs;

— acoustical;

— with vibration.

5.23.3 Optional warning indications

Additional warning indications may be provided such as

— temperature range indicator,

— indicator if the system is not correctly oriented in the coordinate system, especially for whole-body measurements,

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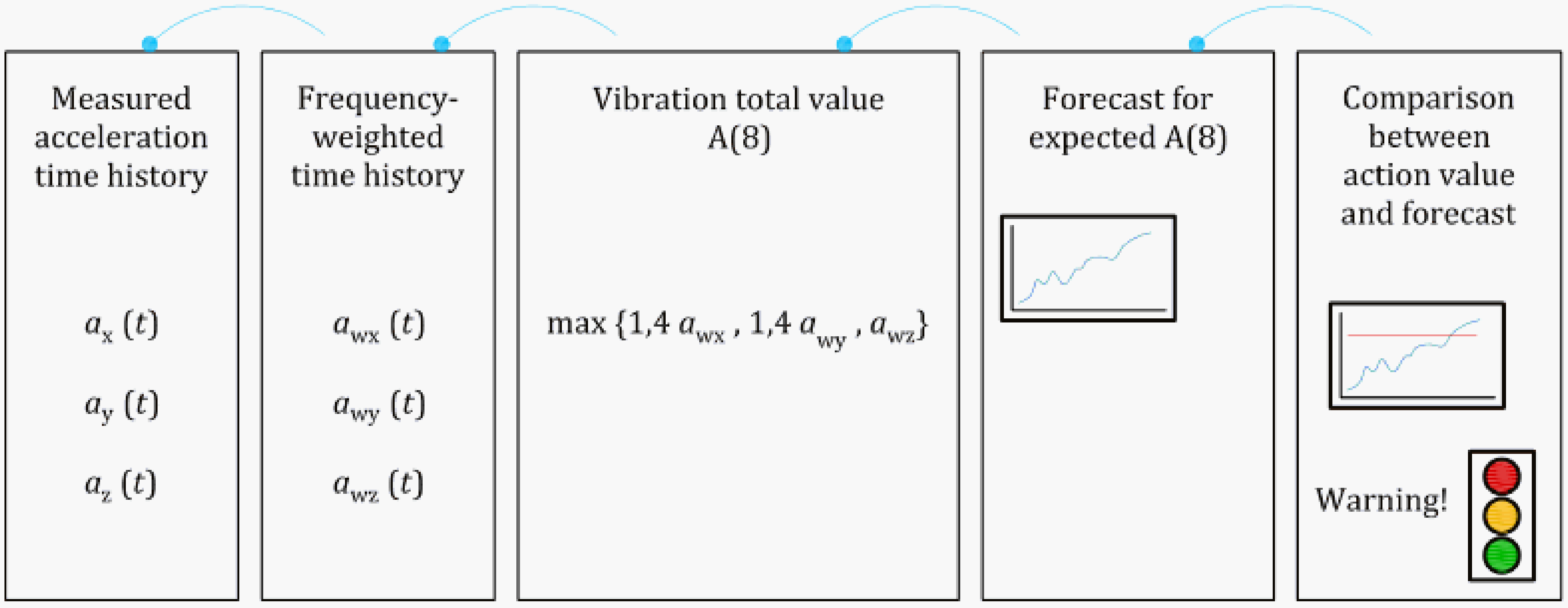
— for PVEM with the capability to identify the assigned operator, a warning if not the right operator is using the machine, and

— warning if the action value could be reached.

A PVEM can be capable to give warnings if the relevant action value could be reached during or at the end of the working shift. It is the responsibility of the manufacturer to provide suitable algorithms that cover this requirement. For A(8) evaluation, Figure 3 shows the principle of detection for whole-body vibration whereas Figure 4 is applicable to hand-arm vibration.



Key

a_x acceleration in x direction

a_y acceleration in y direction

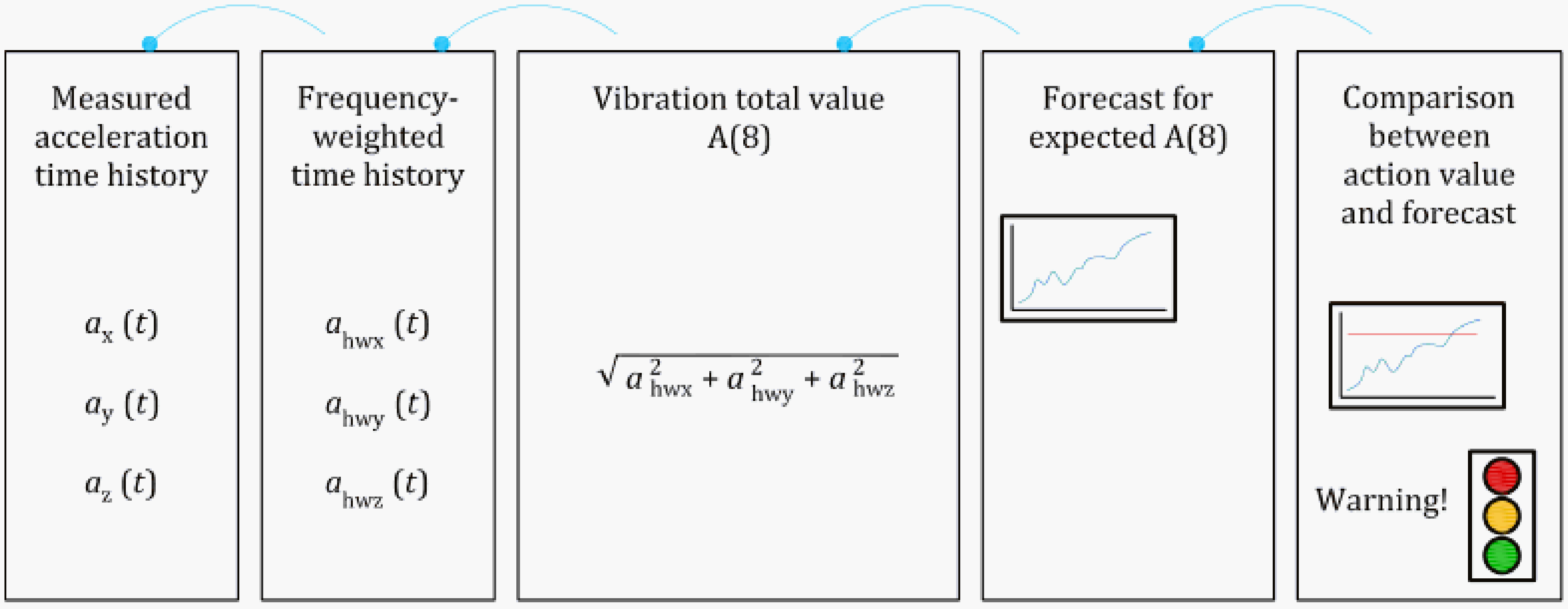
a_z acceleration in z direction

a_{wx} frequency weighted acceleration in x direction

a_{wy} frequency weighted acceleration in y direction

a_{wz} frequency weighted acceleration in z direction

Figure 3 — Example of warning for whole-body vibration if the action value will be reached



Key

a_x acceleration in x direction

a_y acceleration in y direction

a_z acceleration in z direction

a_{hwx} frequency weighted acceleration in x direction

a_{hwy} frequency weighted acceleration in y direction

a_{hwz} frequency weighted acceleration in z direction

Figure 4 — Example of warning for hand-arm vibration if the action value will be reached

5.24 Human interface and ergonomic aspects

Compared to noise measurement at the workplace using a personal sound exposure meter, vibration measurement tends to interfere with the work task execution. Especially with hand-arm vibration, the vibration transducer mounted on a machine or used with gloves can disturb the operator while

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performing his work task (see ISO 5349-2:2001, 6.1.4.1). The PVEM manufacturer, thus needs to carefully consider the ergonomic aspects of their design that would hinder the user in their task.

NOTE For information on mounting systems, see ISO 8041-1:2017, Annex F.

6 Mounting

The instrument documentation shall state the range of applications for which any supplied mounting system is suitable and shall specify any circumstances in which the use of the mounting system is likely to result in greater uncertainty of measurement.

7 Environmental and electromagnetic criteria

7.1 General

All specifications for the sensitivity to various operating environments apply to, and are relative to, the mechanical sensitivity under the reference environmental conditions and at the calibration check frequency. The instrument documentation shall state the typical time interval that is required for the PVEM to stabilize after changes in environmental conditions.

7.2 Air temperature

The influence of variations in air temperature on the mechanical sensitivity is specified over the range of air temperatures from −10 °C to 50 °C. The influence of variations in air temperature on the vibration sensitivity shall be no more than ±5 % over the specified temperature ranges.

The specification for the influence of variations in air temperature applies to a complete PVEM or to those components of a PVEM that may be exposed routinely to large variations in air temperature.

For those components of a PVEM designated in the instrument documentation as intended to be located in an environmentally controlled enclosure (e.g. indoors), the temperature range may be restricted to 5 °C to 30 °C. The restricted range of temperature does not apply to a complete PVEM.

Over the ranges of air temperature specified, the linearity error at the reference frequency and the extent of the linear operating range on the reference measurement range shall remain within the tolerance limits given in 5.7.

7.3 Surface temperature

The influence of variations in measurement surface temperature on the vibration sensitivity is specified over the range of surface temperatures from −10 °C to 50 °C. The influence of variations in surface temperature on the vibration sensitivity shall be no more than ±4 % over the specified temperature range.

The specification for the influence of variations in surface temperature applies to the accelerometer, cables and mounting systems that can come into direct contact with vibrating surfaces.

Over the range of surface temperature given in this subclause, the linearity error at the reference frequency and the extent of the linear operating range on the reference measurement range shall remain within the tolerance limits given in 5.7.

7.4 Electrostatic discharge

The influence of electrostatic discharges on the operation of a PVEM, or applicable components of a PVEM, shall be reduced as far as is practicable.

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A PVEM shall continue to operate as intended after exposure to a contact discharge of electrostatic voltage of up to ±4 kV or to an air discharge of electrostatic voltage of up to ±8 kV. The polarity of the electrostatic voltage is relative to earth ground.

Exposure to the electrostatic discharges specified in this subclause shall cause no degradation of performance or loss of function in the PVEM, except as may be specified in the instrument documentation. The instrument documentation may specify that the performance or function of a PVEM can be degraded or lost because of electrostatic discharges. The specified degradation or loss of function shall not include any change of operating state, change of configuration, corruption or loss of any stored data, or permanently reduced operation.

7.5 Radio-frequency emissions and public-power-supply disturbances

The radio-frequency emissions from a PVEM shall be reduced as far as is practicable.

If the PVEM allows the connection of interface or interconnection cables, the instrument documentation shall recommend typical cable lengths and shall describe the nature of all devices to which the cables may be attached.

The level of the radio-frequency electric field strength emitted by the instrument's enclosure ports shall not exceed 30 dB (relative to 1 μV/m) for frequencies from 30 MHz to 230 MHz, and shall not exceed 37 dB for frequencies above 230 MHz and up to 2 GHz. The instrument documentation shall state the operating mode(s) of the instrument, and any connecting devices, which produce the greatest emission of radio-frequency fields.

The maximum disturbance conducted to the public supply of electric power shall be within the quasi-peak and average voltage limits given in Table 10 at an AC power port. If the PVEM conforms to the limit on the average voltage of conducted disturbance when using a quasi-peak measuring device, the PVEM shall be deemed to conform to both the quasi-peak and average voltage limits.

Table 10 — Limits for conducted disturbance to the voltage of a public supply of electric power

Frequency range MHz	**Limits on voltage level of disturbance** dB (re 1 μV)	
	Quasi-peak	Average
0,15 to 0,50	66 to 56	56 to 46
0,50 to 5	56	46
5 to 30	60	50

NOTE 1 See CISPR 16-1-1 for characteristics of quasi-peak measuring receivers.

NOTE 2 The lower limits of voltage level apply at the transition frequencies.

NOTE 3 The voltage level limits decrease linearly with the logarithm of the frequency in the range from 0,15 MHz to 0,50 MHz.

7.6 Immunity to AC power-frequency fields and radio-frequency fields

Exposure of the complete PVEM (or applicable components designated in the instrument documentation) to specified AC power-frequency and radio-frequency fields shall not cause any change in the operating state, or change of configuration, or corruption or loss of any stored data. This requirement applies for any operating mode consistent with normal operation. The instrument documentation shall state the operating mode(s) of the instrument, and any connecting devices, that have the minimum immunity (are most sensitive) to AC power-frequency and radio-frequency fields.

Immunity to AC power-frequency fields applies to exposure to a uniform RMS magnetic field strength of 80 A/m at frequencies of 50 Hz and 60 Hz. The uniformity of the magnetic field strength is established before immersion of the PVEM. The orientation of the instrument in the field shall be that specified in the instrument documentation for maximum sensitivity to AC power-frequency fields.

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Immunity to radio-frequency fields applies over the carrier frequencies range from 26 MHz to 2 GHz, with the signal at the carrier frequency of the radio-frequency field amplitude modulated by a sinusoidal signal at the reference frequency (or frequencies) appropriate to the application of the instrument to a depth of 80 %. When unmodulated and in the absence of the PVEM, the radio-frequency field shall have a uniform RMS electric field strength of 10 V/m.

Note that the instrument documentation may state that the PVEM conforms to the specifications of this document at an unmodulated RMS electric field strength greater than 10 V/m.

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

For instruments with an AC input power port or an AC output power port, immunity to radio-frequency common-mode interference applies over the frequency range from 0,15 MHz to 80 MHz.

For instruments with signal or control ports, where any interconnecting cable between any part of the PVEM exceeds a length of 3 m, immunity to radio-frequency common-mode interference applies over the frequency range from 0,15 MHz to 80 MHz.

NOTE Country-specific regulations can apply (e.g. Directive 2014/53/EU).

7.7 Ingress of water and dust

The PVEM shall be capable of resisting ingress of water and dust. The manufacturer shall specify the IP rating of the instrument. The instrument's IP rating shall be suited to the planned application (e.g. human-vibration exposure assessments in factories might require a rating of IP 65).

NOTE IP ratings for instrument enclosures are specified in IEC 60529.

8 Provision for use with auxiliary devices

If an optional extension cable provided by the manufacturer of the PVEM can be placed between the accelerometer and the other components of the PVEM, the instrument documentation shall provide details of any corrections to be applied to the results of measurements made in this manner.

The instrument documentation shall provide data on the nominal effect of optional accessories supplied by the manufacturer of the PVEM. The data shall apply to all relevant characteristics of the instrument resulting from installation of the accessories. Optional accessories include accelerometer mounting devices and mechanical filters. The instrument documentation shall provide data on the typical effect on sensitivity and frequency responses.

The instrument documentation shall state whether the PVEM conforms to the specifications required by this document when the optional accessory is installed.

The instrument documentation shall provide details regarding the connection of auxiliary devices to the PVEM and the effects, if any, of such devices on the electrical characteristics of the instrument. Auxiliary devices include recorders, printers, computers and display devices (see also 5.2).

9 Instrument marking

An instrument that conforms to all applicable specifications of this document shall be marked or shall display a reference to this document by number and publication date. The marking shall indicate the name or trademark of the supplier responsible for the technical specifications applicable to the complete instrument. In addition, the marking shall include the model designation and the serial numbers.

If the instrument consists of several separate units (see Figure 1), each principal unit or component shall be marked as described in this clause, as practicable. All principal units comprising a complete instrument shall be identified.

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10 Instrument documentation

Instrument documentation shall be supplied with each personal vibration exposure meter that conforms to the specifications of this document.

If the instrument consists of several separate components (see Figure 1), an instrument documentation shall be available for the combination that forms the complete PVEM. The instrument documentation shall describe all necessary components as well as their mutual influence.

All instrument specifications shall be given in SI units.

The instrument documentation shall contain the information specified in ISO 8041-1:2017, Annex G, where they apply to the instrument.

The instrument documentation shall describe the range of typical applications.

The manufacturer shall provide all information required for the verification of the specifications and, if a device has functions according to Annex A, also the description of the applied procedures.

11 Performance testing

Three levels of performance testing are defined in this document:

a) Pattern evaluation (targeted at manufacturers) is a full set of tests on samples of an instrument type. This test which can be performed is used for product type testing or pattern approval of a production series of PVEM. The objective of this test is to demonstrate an instrument design can meet the specifications defined in this document.

b) Periodic verification (targeted at manufacturers and users) is an intermediate set of tests which

— can be performed periodically (e.g. prior to, or at the time of purchase, and at least every 2 years thereafter) to verify that the performance remains within the specifications of this document, and/or

— should be performed following modification (e.g. use of another transducer) or repair that might affect the performance of the instrument.

c) In-situ check (targeted at users) is a minimum level of testing, indicating that a PVEM is likely to be functioning within the required performance specification. These tests shall be carried out immediately before and after measurements are made.

The tests are designed to assess the performance characteristics and specifications defined in Clause 5 to Clause 10. Table 11 shows the relationship between the specifications and associated testing requirements.

For optional features, this document does not specify test procedures.

Table 11 — Summary of features of a PVEM and testing requirements

Relevant features		Testing requirements		
Subclause	**Characteristic**	**Pattern evaluation**	**Periodic verification**	**In-situ check**
5.1	General characteristics	X	X	X
5.2	Display of signal magnitude	X		
5.4	Vibration sensitivity	X	X	X
5.5	Accuracy of indication at reference frequency under reference conditions	X		
5.6	Frequency weightings and frequency responses	X	X	

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Table 11 *(continued)*

Relevant features		Testing requirements		
Subclause	**Characteristic**	**Pattern evaluation**	**Periodic verification**	**In-situ check**
5.7	Amplitude linearity	X	X	
5.8	Instrument noise	X		
5.9	Signal-burst response	X		
5.10	Overload indication	X		
5.12	Time averaging	X		
5.14	Reset	X		
5.15	Timing facilities	X		
5.16	Electrical cross-talk	X		
5.2	Combined axis outputs	X		
5.17	Vibration transducer characteristics	X		
5.18	Power supply	X		
5.19	Operator detection system	X		
5.21	Logging capabilities	X		
5.23.2	Warning indication (mandatory warnings)	X		
Clause 6	Mounting	X		
Clause 7	Environmental and electromagnetic criteria	X		
Clause 8	Provision for use with auxiliary devices	X		
Clause 9	Instrument marking	X	X	
Clause 10	Instrument documentation	X	X	
Optional features				
5.19	Operator identification	No tests specified		
5.20, Annex A	Detection of transient acceleration artefacts			
5.22, Annex B	Contact force measurement			
5.23.3	Warning indication (optional warnings)			
5.24, Annex C	Human interface and ergonomic aspects			

12 Pattern evaluation

12.1 General

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

Conformance to a specification of this document is demonstrated when the result of a measurement of a deviation from a design goal, extended by the actual expanded uncertainty of measurement of the testing laboratory, does not exceed the specified tolerance limits.

Uncertainties of measurement shall be determined in accordance with ISO/IEC Guide 98-3. The actual expanded uncertainties shall be calculated by the testing laboratory, with a coverage factor of no less than 2.

The expanded uncertainties of measurement given in this clause are the maximum permitted for demonstration of conformance, under this clause, to the specifications of this document. Testing

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laboratories shall not perform tests to demonstrate conformance to the specifications of this document if their actual expanded uncertainties of measurement exceed the maximum permitted values.

No test specified in this clause shall be omitted unless the instrument does not possess the facility to be tested.

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

12.2 Testing requirements

Those instruments used for pattern evaluation that affect the uncertainty of test outputs shall hold valid calibrations, traceable to national or internationally recognized standards.

The frequency of the input signals shall be within ±0,2 % of the required value.

The value of mechanical input signals shall be within ±2 % of the required value.

NOTE 1 Currently, the published parts of ISO 16063 do not provide for calibration below 0,4 Hz.

The environmental conditions prevailing at the time of a test shall be within the following ranges:

— air temperature: 20 °C to 26 °C;

— relative humidity: 10 % to 75 % (non-condensing).

The total distortion, d, for sinusoidal mechanical vibration test inputs shall be no greater than 5 %.

The total distortion, d, for sinusoidal electrical test inputs shall be no greater than 0,1 %.

Total distortion, d, expressed as a percentage, is defined as shown by Formula (7):

$$d=\frac{\sqrt{a_{\text{tot}}^2-a_1^2}}{a_1}\times 100 \qquad (7)$$

where

a_1 is the RMS acceleration at the driving frequency;

a_{tot} is the total band-limited RMS acceleration (including a_1).

12.3 Submission for testing

The PVEM shall be submitted for testing together with its documentation and all items or accessories that are identified in the instrument documentation as integral components of the complete instrument in its configuration for normal use. Examples of additional items or accessories include an accelerometer, mounting device and cable.

The instrument shall be submitted for testing with equipment (e.g. adaptors) suitable for enabling the input and output of electrical signals.

A field vibration calibrator should be supplied with the PVEM.

12.4 Marking of the instrument and information in the instrument documentation

It shall be confirmed that the instrument is marked according to the specifications of Clause 9.

Before conducting any tests, it shall be confirmed that the instrument documentation contains all the information required by Clause 10, appropriate to the facilities provided by the PVEM.

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After completion of all tests, the information shall be reviewed to ensure that it is correct and within the appropriate tolerance limits.

12.5 Mandatory facilities and general requirements

A PVEM shall be confirmed to conform to the requirements of 5.1.

For instruments with multiple measurement ranges, it shall be confirmed that the measurement range overlap conforms to the specifications of 5.7.

The display shall be confirmed to conform to the specifications of 5.2.

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

If the instrument does not satisfy the requirements listed in this clause, tests shall not be performed to demonstrate conformance to the performance specifications of this document.

12.6 Initial instrument preparation

Before conducting any tests, the instrument shall be given a power supply within the operating limits specified by the manufacturer. The instrument, transducer and the field vibration calibrator (if supplied) shall be visually inspected and all controls operated to ensure they are in working order.

The procedure given in the instrument documentation shall be followed to set the vibration sensitivity of the instrument at the calibration check frequency. Any adjustments required by 5.4 and given in the instrument documentation shall be applied to adjust the sensitivity of the instrument to display the correct vibration value under reference environmental conditions.

12.7 Indication at the reference frequency under reference conditions

The error in the indication of the reference acceleration value at the reference frequency (see Table 1) shall be determined from the difference between the vibration value displayed by the instrument and the corresponding vibration value measured by an appropriately calibrated reference vibration transducer at the same measurement point.

The error, ε, of the test measurement, a_{test}, is expressed as a percentage of the reference vibration transducer measurement, a_{ref}, as shown by Formula (8):

$$\varepsilon = \frac{a_{test} - a_{ref}}{a_{ref}} \times 100\,\% \tag{8}$$

NOTE The error, ε, is a relative measure, i.e. a relative error expressed as percentage.

The reference vibration transducer shall be used to measure the value of the mechanical vibration input generated at the reference vibration value and reference frequency, before measuring the vibration magnitude with the PVEM. For these measurements, the PVEM shall be set to the reference measurement range, band-limiting frequency weighting and linear time averaging and with a measurement duration sufficient for the indicated values to stabilize (for low-frequency testing, this duration can be as much as 30 s for hand-arm vibration, 1 min for whole-body, and 5 min for low-frequency whole-body applications). The value of the input signal plus background noise shall be at least ten times the value of the background noise as measured by the PVEM.

A minimum of three measurements of error of indication shall be obtained. For each measurement, a time interval not less than that stated in the instrument documentation for the instrument's settling time shall be allowed for the instrument to reach equilibrium with the prevailing environmental conditions before any indication is recorded. The difference between the greatest and the smallest of the three measurements shall not exceed 3 %.

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The arithmetic average of the error of indication measurements shall be within the applicable tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

For each frequency weighting provided, a steady sinusoidal electrical signal shall be applied to the electrical input facility at the appropriate reference frequency. With an input signal adjusted to indicate the reference vibration value on the reference measurement range with band-limiting frequency weighting, the indicated frequency-weighted vibration values shall equal the indicated band-limited weighted vibration value multiplied by the appropriate weighting factor (see Table 1) within the tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

For an instrument where time weightings are provided, a steady sinusoidal electrical signal shall be applied to the electrical input facility at the reference frequency. The amplitude of the input signal shall be adjusted to give an indication of the reference vibration value on the reference measurement range with the PVEM set to band-limiting frequency weighting. With the same input signal, the indicated vibration values on each time weighting shall equal the indicated reference vibration value within the tolerance limits of Table 2. The maximum expanded uncertainties of measurement are 2 %.

12.8 Electrical cross-talk

For instruments with more than one measurement channel (e.g. triaxial measurement instruments), tests shall be carried out of the electrical interference between the channels.

All channels shall be set to the reference measurement range. An electrical input shall be applied to each channel in turn at the reference frequency; the inputs to all remaining channels shall be terminated by substitute impedances. The amplitude of the test signal shall be within the upper 5 dB of the reference measurement range. The output of all channels shall be monitored during the tests.

The output from all channels shall not exceed the requirements of 5.16.

12.9 Vibration transducer

The vibration transducer characteristics (see ISO 8041-1:2017, Annex E) of the accelerometer shall be tested according to the relevant parts of ISO 5347 and ISO 16063.

12.10 Amplitude linearity

12.10.1 Electrical tests of amplitude linearity

The electrical tests of amplitude linearity of a PVEM shall be carried out with steady sinusoidal electrical signals at the frequencies indicated in Table 12. Amplitude linearity shall be tested with the instrument set to time-averaged measurement with a band-limiting frequency weighting.

Table 12 — Amplitude linearity test frequencies and acceleration value increments

Application	Test frequencies[a] Hz	Acceleration increment dB	
		Within 5 dB of overload and lower boundary of measurement range	At all other values
Hand-arm	8; 80; 800	1	5
Whole-body	1; 4; 16; 63	1	5
Low-frequency whole-body	0,2; 0,4	1	5

[a] Nominal centre frequencies are shown. The exact one-third-octave band centre frequencies shall be used, e.g. “8 Hz” represents the band centred on $10^{9/10}$ Hz ≈ 7,943 Hz.

For some frequencies, the amplitude may be reduced if necessary.

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

At any of the frequencies, the starting point for amplitude linearity tests on any measurement range shall be the reference vibration value multiplied by the nominal attenuation factor introduced by the measurement range control relative to the setting on the reference measurement range.

On the reference measurement range, the value of the test frequency input signal shall be increased in the increments specified in Table 12 from the specified lower boundary [see ISO 8041-1:2017, G.2 j)] of this measurement range up to the input signal value that causes the first indication of overload. The signal shall then be decreased in increments specified in Table 12 from the signal value that caused the first indication of overload down to the specified lower boundary. For each input signal value, the indication on the instrument's display device and the input signal value shall be recorded.

For each test frequency input signal value, from the specified lower boundary of the reference measurement range until the first indication of overload, amplitude linearity errors shall be within the applicable tolerance limits of 5.7. The extent of the reference frequency linear operating range on the reference measurement range shall comply with the linear operating range requirements of 5.7 between the nominal vibration magnitudes specified for the upper and lower boundaries. The maximum expanded uncertainties of measurement are 2 %.

Following tests on the reference measurement range, the amplitude linearity shall be tested on any additional measurement ranges. Tests shall be carried out at the frequencies and increments specified in Table 12 from the starting point down to the lower boundary and up to the upper boundary specified for each measurement range.

On each additional measurement range of the PVEM, the amplitude linearity errors shall be within the applicable tolerance limits of 5.7 over the extent of the linear operating ranges specified in the instrument documentation and until the first indications of overload. The maximum expanded uncertainties of measurement are 2 %.

For instruments with time-averaging facilities for which the linear operating range is greater than the indicator display range, linearity errors above the top of the display range may be measured by using tone bursts extracted from the steady input signals. The duration of the tone bursts shall be no less than 30 s for hand-arm vibration, 5 min for whole-body vibration (this test is not practical for low-frequency whole-body vibration). Integration times shall be greater than the duration of the tone burst.

12.10.2 Mechanical tests of amplitude linearity

The mechanical tests of amplitude linearity of an instrument shall be carried out with steady sinusoidal mechanical signals at the frequencies indicated in Table 12. Amplitude linearity shall be tested with the instrument set to time-averaged measurement with a band-limiting frequency weighting. Amplitude linearity shall be determined as the indication on the display device minus the vibration measured by an appropriately calibrated reference vibration transducer. The vibration transducers shall be mounted in accordance with the calibration procedure specified in ISO 16063-21.

At any frequency, the starting point for amplitude linearity tests on any measurement range shall be the reference vibration value multiplied by the nominal attenuation factor introduced by the measurement range control relative to the reference measurement range.

Tests of amplitude linearity shall begin with signals at the reference frequency applied to the base of the vibration transducer. The input signal shall be adjusted to display the reference vibration value on the reference measurement range.

The mechanical amplitude linearity shall be tested over a range of no less than 40 dB.

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On the reference measurement range, the value of the test frequency input signal shall be increased in the increments specified in Table 12 from the specified lower boundary of this measurement range up to the input signal value that is the lowest of

a) the first indication of overload on the PVEM,

b) the maximum vibration capability of the input device, or

c) the maximum of the linear vibration amplitude range of the reference transducer.

The signal shall then be decreased in increments specified in Table 12 from that maximum signal value down to the input signal that is the greatest of

— the specified lower boundary of the PVEM,

— the minimum vibration amplitude capability of the input device, or

— the minimum of the linear vibration amplitude range of the reference transducer.

For each input signal value, the indication on the instrument's display device and the value measured by the reference transducer shall be recorded.

The amplitude linearity of the laboratory reference vibration transducer shall be taken into account when establishing the constant vibration value at different vibration amplitudes.

For each test frequency input signal value, from the specified lower boundary of the reference measurement range until the maximum signal value specified above, amplitude linearity errors shall be within the applicable tolerance limits of 5.7. The extent of the reference frequency linear operating range on the reference measurement range shall comply with the linear operating range requirements of 5.7 between the nominal vibration magnitudes specified for the upper and lower boundaries. The maximum expanded uncertainties of measurement are 3 %.

Following tests on the reference measurement range, the amplitude linearity shall be tested on any additional measurement ranges. Tests shall be carried out at the frequencies and increments specified in Table 12 from the starting point down to the lower boundary and up to the upper boundary specified for each measurement range.

On each additional measurement range, amplitude linearity errors shall be within the applicable tolerance limits of 5.7 over the extent of the linear operating ranges specified in the instrument documentation. The maximum expanded uncertainties of measurement are 4 %.

12.11 Frequency weightings and frequency responses

12.11.1 General

The procedure described in this subclause for assessing the frequency weighting and frequency response characteristics assumes that the PVEM does not have an electrical output. If an electrical output is available and used for the tests, preliminary tests shall be performed to determine the correspondence between the values of frequency-weighted vibration indicated on the display device and the voltages at the electrical output. No attempt shall be made to account for linearity errors in any test of frequency weighting.

For each application (hand-arm, whole-body and low-frequency whole-body) for which frequency weightings are provided in the instrument, one frequency weighting shall be selected for testing with both sinusoidal mechanical and electrical signals. Other frequency weightings shall be tested using either mechanical or electrical signals.

Where possible, tests of frequency weightings and frequency responses shall be performed on the reference measurement range. Where the testing laboratory considers that the ability of an instrument to conform to the specifications for frequency weighting or frequency response might be influenced by the setting of the measurement range control, then additional tests shall be performed.

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All measurements shall be performed on measurement ranges where linearity errors are within the applicable tolerance limits given in 5.7.

The tests of frequency response shall be made in steps of not more than one-third octave across the frequency ranges specified in Table 13.

Table 13 — Test frequencies for mechanical and electrical frequency response tests

Application	Test one-third-octave-band frequency range[a] Hz	
	Electrical tests	Mechanical tests
Hand-arm	4 to 2 000	8 to 2 000
Whole-body	0,25 to 160	0,5 to 160
Low-frequency whole-body	0,05 to 1	0,4 and 0,5

[a] The range of nominal centre frequencies is shown. The exact one-third-octave band centre frequencies shall be used, e.g. "8 Hz" represents the band centred on $10^{9/10}$ Hz ≈ 7,943 Hz.

NOTE 1 The errors, ε, mentioned in 12.11 are relative measures, i.e. relative errors expressed as percentages.

NOTE 2 For testing the magnitude frequency response, see 12.11.2 and 12.11.3. For testing the phase frequency response, see ISO 8041-1:2017, Annex H.

12.11.2 Mechanical tests of frequency response

The mechanical frequency response of the PVEM shall be determined by comparison with unweighted acceleration measurements made by an appropriately calibrated laboratory reference vibration transducer. The error in frequency response is the indication of frequency-weighted acceleration value on the PVEM minus the vibration value measured by the laboratory reference vibration transducer when multiplied by the appropriate frequency weighting factor. The vibration transducers shall be mounted in accordance with the calibration procedure specified in ISO 16063-21.

At the reference frequency, the input mechanical vibration shall be adjusted such that the indication of band-limited vibration on the PVEM is 20 dB above the lower limit of the specified linearity range. The band-limited acceleration value of this input signal, a_{in}, shall be used as a reference input value for subsequent tests.

At each test frequency, the input signal level shall be adjusted to give the same input vibration value, a_{in}, as measured by the laboratory reference vibration transducer. The value of the input vibration acceleration and the indication of the PVEM, a_{ind}, shall be noted at each of the test frequencies defined in Table 13 for mechanical tests.

The frequency-response error at frequency f, $\varepsilon(f)$, expressed as a percentage, is given by Formula (9):

$$\varepsilon(f)=\frac{a_{\text{ind}}(f)-a_{\text{in}}w(f)}{a_{\text{in}}w(f)}\times 100 \qquad (9)$$

where $w(f)$ is the frequency weighting factor at frequency f.

The frequency response of the laboratory reference vibration transducer shall be taken into account when establishing the constant vibration value at different frequencies.

If a constant vibration value cannot be maintained over the complete range of frequencies, signal values displayed by the instrument shall be corrected, as required, for the differences between the vibration value measured by the laboratory reference vibration transducer at a test frequency and at the reference frequency.

The maximum expanded uncertainties of measurement are 4,5 % for all frequencies in the appropriate nominal frequency range.

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Where separate tests are carried out on the vibration transducer and the electrical part of the instrument, then the error of the frequency weighting, ε, at frequency, f, is given by Formula (10):

$$\varepsilon(f)=\varepsilon_t(f)+\varepsilon_e(f) \tag{10}$$

where

ε_t is the error of the vibration transducer response;

ε_e is the error of the electrical part of the instrument.

In both cases, the error combines the apparent error of the measured result, ε_m, with the expanded uncertainty of measurement, u_m, as shown by Formula (11):

$$\varepsilon_t=\sqrt{\varepsilon_m^2+u_m^2} \tag{11}$$

ISO 8041-1:2017, Annex F, provides test information for mounting systems where these are provided with the instrument.

12.11.3 Electrical tests of frequency response

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

At the reference frequency, f_{ref}, the input electrical signal shall be adjusted such that the indication of band-limited vibration on the PVEM is 20 dB above the lower limit of the specified linearity range. The indicated frequency-weighted value, a_{ind}, of this input signal shall be used as a reference value for subsequent tests.

At each test frequency, the input RMS signal value u_{in} shall be adjusted such that the same indicated frequency-weighted value, a_{ind}, is displayed. The value of the input signal and the indication of the PVEM shall be noted at each of the test frequencies defined in Table 13 for electrical testing.

The electrical component of the frequency response error at frequency f, $\varepsilon_e(f)$, expressed as a percentage, is given by Formula (12)

$$\varepsilon_e(f)=\left[a_{ind}-\frac{u_{in}(f)}{S}w(f)\right]\Big/\left[\frac{u_{in}(f)}{S}w(f)\right]\times 100\ \%=\left[\frac{u_{in}(f_{ref})\,w(f_{ref})}{u_{in}(f)\,w(f)}-1\right]\times 100\ \% \tag{12}$$

where

$w(f)$ is the frequency weighting factor at frequency f;

S is the sensitivity, given by Formula (13):

$$S=\frac{u_{in}(f_{ref})w(f_{ref})}{a_{ind}} \tag{13}$$

At any frequency, the RMS value of the input signal plus instrument noise shall be at least ten times the RMS value of the instrument noise.

If the same indicated vibration value cannot be maintained over the complete range of frequencies, signal values displayed by the instrument shall be corrected, as required, for the differences between the vibration value of the input electrical signal at a test frequency and at the reference frequency. Signal values displayed by the instrument shall also be corrected, as required, for any nonlinearity between the indication at the test frequency and the indication at the reference frequency.

The maximum expanded uncertainties of measurement are 3 % for all frequencies in the appropriate nominal frequency range.

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12.11.4 Conformance

For those frequency weightings tested using the mechanical tests, the frequency weighting error is provided directly from the test, i.e. $\varepsilon(f)$ in Formula (9). For frequency weightings tested only using the electrical test, the overall frequency weighting error shall account for the frequency response of the vibration transducer, $\varepsilon_t(f)$. Values for $\varepsilon_t(f)$ are obtained by subtracting the error $\varepsilon_e(f)$ from the result of the mechanical test, $\varepsilon(f)$, for the frequency weighting that has been mechanically tested, see Formula (10).

EXAMPLE An instrument provides two whole-body weightings: W_d and W_k. W_d is selected for both mechanical and electrical frequency response testing. The response of the vibration transducer is given by the difference between the mechanical and electrical test results for W_d. This vibration transducer response is added to the electrical response for W_k to give the overall frequency response of the instrument for W_k.

For all available frequency weightings, the error of the overall frequency response of the instrument shall be within the applicable tolerance limits specified in 5.6. The maximum expanded uncertainties of measurement are 5 % for all frequencies in the appropriate nominal frequency range.

Other optional frequency responses provided shall conform to the design goals and tolerance limits stated in the instrument documentation.

12.12 Instrument noise

The typical value of instrument noise shall be determined from the arithmetic average of ten measurements with the vibration transducer of the instrument fitted to a non-vibrating object that does not add significantly to the indicated vibration value. Tests shall be carried out for time-averaged vibration for which the averaging time shall be stated and shall be at least 1 min for hand-arm vibration, 5 min for whole-body vibration, and 30 min for low-frequency whole-body applications.

12.13 Signal-burst response

With the instrument set to the reference measurement range and the applicable band-limiting weighting, a steady sinusoidal electrical signal at the frequency specified in Table 6 shall be applied and the signal value adjusted to obtain an indication at 50 % of the specified upper boundary of the linear operating range. The signal bursts specified in Table 6 shall then be applied to all available time and frequency weightings.

The fall time of the saw-tooth burst wave shall be no more than $1/(5\,f_2)$, where f_2 is the upper limiting frequency of the band-limiting component of the appropriate frequency weighting, defined in Table 3.

High-frequency switching transients can be produced when generating the saw-tooth wave. To avoid the test being affected by these, a single-pole low-pass filter can be necessary between the signal generator and the PVEM. The cut-off frequency should be high enough to avoid influencing the test results, e.g. $100\,f_2$.

Measurements of signal-burst response shall be repeated with the value of the steady input signal reduced by factors of 10 down to an input signal value that gives an indication at least three times greater than the specified lower boundary for the linear operating range.

Measurements of single-cycle signal-burst response shall be repeated with the magnitude of the signal bursts increased until the first indication of overload.

The vibration values indicated in response to the signal bursts, relative to the values of the vibration amplitude of the input signal, shall be as specified in Table 7, 8 or 9, as appropriate for the application. The signal-burst response errors shall be within the tolerance limits given in Tables 7, 8 and 9. The maximum expanded uncertainties of measurement are 3 %.

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12.14 Overload indication

Overload indications shall be tested by using mechanical signals at the reference frequency (see 13.8.1 or 13.8.2). With the instrument set to the reference measurement range and band-limited frequency weighting, the signal value shall be increased until the first indication of overload. The input signal shall be measured with a reference transducer. In each case, the lowest input signal value that causes the first indication of overload shall be recorded. The maximum expanded uncertainties of measurement are 2 %.

12.15 Reset

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

12.16 Combined axis outputs

This test ensures that multi-axis inputs are combined in accordance with the appropriate measurement standard when the combined axis output is displayed, e.g. root-sum-of-squares vibration total value or the total VDV.

The instrument shall be set to the reference measurement range. An electrical input signal at the reference vibration value shall be applied to each axis in turn. The indicated value for each axis shall be noted and used to calculate a combined axis result in accordance with the appropriate International Standards (ISO 2631-1, ISO 2631-2, ISO 2631-4 and ISO 5349-1). The input signal shall then be applied simultaneously to all three input channels; the indicated combined axis value shall be equal to the calculated result to within ±3 %.

The signal on one channel shall be inverted, i.e. 180° phase change. The indicated value following the signal inversion shall not change by more than 2 %.

For whole-body vibration, the weightings used for *x*-, *y*- and *z*-axes and the multiplying factors, *k*, used for combining single-axis data, are dependent on the application, e.g. health. ISO 2631-1 should be used to determine the expected outputs.

12.17 AC electrical output

Not applicable for PVEM.

12.18 Timing facilities

The minimum averaging time for the measurement of time-averaged vibration values shall be verified to be no greater than the minimum averaging time specified in the instrument documentation. The maximum averaging time for the measurement of time-averaged vibration values shall be verified to be not less than the maximum averaging time specified in the instrument documentation.

A measurement shall be carried out over 2 000 s and the elapsed time shall be within ±2 s, i.e. ±0,1 %. The maximum expanded uncertainties of measurement are 0,01 %.

12.19 Power supply

With the field vibration calibrator supplied with the personal vibration exposure meter applied to the accelerometer in part A of the PVEM, the indicated vibration signal value on the reference measurement range shall be recorded with the power supply delivering the nominal voltage and then delivering the minimum voltage to the instrument as specified in the instrument documentation. The indicated signal values shall be the same within the tolerance limits of 5.18.

NOTE The term power supply includes batteries.

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12.20 Environmental, electrostatic and radio-frequency tests

12.20.1 General

A complete PVEM shall conform to all specifications of this clause that apply to the intended use of the instrument. For conformance to the specifications of this clause, the accelerometer shall be connected to the instrument in accordance with the normal mode of operation stated in the instrument documentation.

Each specification of sensitivity to an operating environment applies to an instrument that is turned on and set to perform a measurement in a typical manner.

Before conducting, but not during, the environmental, electrostatic and radio-frequency tests, the indication at the calibration frequency shall be checked by application of the field vibration calibrator specified in 5.4 and adjusted, if necessary, to indicate the reference vibration value under reference environmental conditions. The adjustment shall use the procedure given in the instrument documentation.

The effect of environmental conditions on the magnitude produced by the field vibration calibrator, relative to the vibration value produced under reference environmental conditions, shall be accounted for in accordance with the procedure given in the instrument documentation.

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

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

12.20.2 Expanded uncertainties for measurements of environmental conditions

The actual expanded uncertainty of measurement shall not exceed 0,5 °C for measurements of air temperature and 10 % for measurements of relative humidity.

12.20.3 Acclimatization requirements for tests of the influence of air temperature and relative humidity

The field vibration calibrator and the instrument (or relevant components) shall be placed in an environmental chamber to test the influence of air temperature and relative humidity on the PVEM.

For tests of the influence of air temperature and relative humidity, the accelerometer shall be removed from the field vibration calibrator and the power to both instruments shall be switched off during an acclimatization period.

The field vibration calibrator and PVEM shall be permitted to acclimatize at the reference environmental conditions for at least 12 h.

After completion of an acclimatization period, the accelerometer shall be fitted on the field vibration calibrator and the power to both instruments shall be switched on.

12.20.4 Test of the influence of air temperature and relative humidity combined

Following the acclimatization procedures described in 12.20.3, the vibration value indicated in response to application of the field vibration calibrator shall be recorded for the following combinations of air temperature and relative humidity. For a PVEM where all components can be operated under any combination of air temperature and relative humidity covered by the specifications of 7.2, the target test conditions are as follows:

— reference air temperature and reference relative humidity;

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— air temperature of −10 °C and relative humidity of 65 %;

— air temperature of 5 °C and relative humidity of 25 %;

— air temperature of 40 °C and relative humidity of 90 %;

— air temperature of 50 °C and relative humidity of 50 %.

For each test condition, the deviation of the indicated vibration value from the vibration value indicated for reference air temperature and reference relative humidity shall be not more than that specified in 7.2.

12.20.5 Influence of surface temperature

At reference air temperature and humidity, and following acclimatization, the vibration value indicated in response to application of a vibration signal at the reference value and reference frequency shall be recorded for the following surface temperatures. The accelerometer on its specified mounting device shall be mounted directly onto a surface which can be temperature controlled to ±5 °C. Use the following surface temperatures:

— reference temperature;

— surface temperature of −10 °C;

— surface temperature of 5 °C;

— surface temperature of 40 °C;

— surface temperature of 50 °C.

For each test condition, the deviation of the indicated vibration value from the vibration value indicated for reference air temperature and reference relative humidity shall be no more than that specified in 12.2.

12.20.6 Influence of electrostatic discharges

The equipment required to determine the influence of electrostatic discharges on the operation of a PVEM shall conform to the specifications given in IEC 61000-4-2:2008, Clause 6. The test set-up and test procedure shall be in accordance with the specifications given in IEC 61000-4-2:2008, Clauses 7 and 8.

Electrostatic discharge tests shall be conducted with the PVEM operating and set to be most susceptible to electrostatic discharge, as determined by preliminary testing. Accelerometers shall be connected to all input channels. The instrument configuration at the time of testing shall be recorded.

Discharges of electrostatic voltages shall not be made to electrical connector pins that are recessed below the surface of a connector or the PVEM.

Electrostatic discharges of the voltages and polarities specified in 7.4 shall be applied ten times by contact and ten times through the air. Discharges shall be applied to any point on the instrument that is considered appropriate by the testing laboratory, see IEC 61000-4-2. The points shall be limited to those that are accessible during normal usage. If the user requires access to points inside the instrument, those points shall be included unless the instrument documentation prescribes precautions against damage by electrostatic discharges during this access.

Care should be taken to ensure that any effects of a discharge to the instrument are fully dissipated before repeating the application of a discharge.

With the instrument set for the reference range, the voltage of the contact and air discharges shall be the maximum positive and the maximum negative voltage.

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After a discharge, the PVEM shall return to the same operating state as before the discharge. Any data stored by the instrument before the discharge shall be unchanged after the discharge. Unquantified changes in the performance of the instrument are permitted when a discharge is applied.

12.20.7 Radio-frequency emissions and public-power-supply disturbances

Radio-frequency field-strength emission levels, in decibels relative to 1 µV/m, shall be measured with a quasi-peak-detector instrument for the frequency ranges specified in 7.5. Measuring receivers, antennae and test procedures shall be as specified in CISPR 22:2008, Clause 10. All emission levels shall conform to the specifications given in 7.5. Environmental conditions prevailing at the time of the tests shall be recorded. Radio-frequency emission tests shall be conducted with the PVEM operating, powered by its preferred supply, and set to the mode, as stated in the instrument documentation, which produces the greatest radio-frequency emissions.

All fixtures and fittings used to maintain the position of the instrument shall be designed to have a negligible influence on the measurement of radio-frequency emissions from the instrument.

Initially, the radio-frequency emission levels shall be measured over the frequency ranges specified in 7.5 with the PVEM in the reference orientation. The accelerometer, attached by the appropriate cable, shall be positioned centrally above the case of the instrument, at a height of approximately 250 mm. If the cable is longer than 250 mm, then it shall be folded back on itself, in a figure-of-eight pattern with an even number of folds of equal length and with all parts secured together at each end of the folds and in their centre.

While maintaining the accelerometer-cable-to-instrument-case arrangement specified in this subclause, the radio-frequency emission levels shall be measured in at least one other plane. The other planes shall be approximately orthogonal to the principal plane of the reference orientation, within the limits of positioning for the system employed to measure radio-frequency emission levels.

If the PVEM has any connection device that permits attachment of interface or interconnection cables, radio-frequency emission levels shall be measured with cables connected to all available connection devices. The lengths of the cables shall be as recommended in the instrument documentation. Cables shall not be terminated and shall be arranged as described in CISPR 22:2008, 8.2, unless the manufacturer of the instrument also supplies the device connected to the instrument by a cable, in which case the radio-frequency emission levels shall be measured with all items connected together.

Where several connections can be made to the same connection device, radio-frequency emission levels shall be measured with the configuration specified in the instrument documentation as producing the greatest radio-frequency emission levels. Other configurations with the same, or lower, radio-frequency emission levels may be included in the instrument documentation in a list of compliant configurations, without further testing if the tested configuration fully conforms to the limits of 7.5.

For PVEM that are operated from a public power supply, the disturbance to the public power supply shall be measured as described in CISPR 22:2008, Clause 9, and shall conform to the specifications of 7.5 and the conducted-disturbance limits given in Table 10.

12.20.8 Immunity to AC power-frequency fields and radio-frequency fields

The instrument shall be operating while powered by the preferred supply for tests of conformance of immunity to AC power-frequency fields and radio-frequency fields.

The immunity of a PVEM to AC power-frequency and radio-frequency fields shall be demonstrated with a vibration transducer connected to the PVEM. A mechanical vibration shall be applied to the vibration transducer. The vibration shall be sinusoidal vibration at the reference frequency. With no AC power-frequency or radio-frequency field applied, the band-limited time-averaged vibration value of this test signal shall be as indicated in Table 14. The vibration value shall be indicated on the measurement range for which the lower boundary is closest to, but not greater than, the boundary shown in Table 14, if more than one measurement range is provided.

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Table 14 — Immunity test values for AC power-frequency and radio-frequency fields

Application	Vibration signal value m/s²	Maximum value of lower boundary of measurement range m/s²
Hand-Arm	2	1
Whole-body	0,2	0,1
Low-frequency whole-body	0,2	0,1

The vibration signal shall be applied to the accelerometer in such a manner as to cause no interference with the applied AC power-frequency or radio-frequency field. Also, the method of applying the vibration signal shall not interfere with normal operation of the instrument, or with the instrument's susceptibility to the power-frequency or radio-frequency field.

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

For instruments with an AC input power port and, if available, an AC output power port, immunity to radio-frequency common-mode interference shall be demonstrated over the frequency range from 0,15 MHz to 80 MHz. The radio-frequency field shall be 80 % amplitude-modulated by a sinusoidal signal at the reference frequency for the measurement application. When unmodulated, the RMS radio-frequency voltage shall be 10 V when emitted from a 150 Ω source. Immunity to fast transients on the power supply shall apply for a signal having a 2 kV peak voltage and a repetition frequency of 5 kHz in accordance with IEC 61000-6-2:2016, Table 4. Additional specifications for immunity to voltage dips, voltage interruptions and voltage surges shall be as described in IEC 61000-6-2:2016, Table 4.

For instruments with signal or control ports, where any interconnecting cable between any part of the PVEM exceeds a length of 3 m, the specifications of IEC 61000-6-2:2016, Table 2, apply for immunity to radio-frequency common mode interference over the frequency range from 0,15 MHz to 80 MHz for a RMS voltage of 10 V when unmodulated. Specifications for immunity to fast transients on the public-power-supply system shall apply for a signal having a 1 kV peak voltage and a repetition frequency of 5 kHz in accordance with IEC 61000-6-2:2016, Table 2.

Testing of the PVEM shall be in accordance with IEC 61000-4-6.

The instrument documentation may state that the PVEM conforms to the specifications for exposure to AC power-frequency and radio-frequency fields at an indicated vibration that is less than that shown in Table 14. In this case, the instrument shall conform to the applicable tolerance limits for all vibration values less than the test value shown in Table 14 down to the stated lower value. This requirement applies to all measurement ranges for all specifications. The lower value shall be stated in the instrument documentation and shall apply to all modes of operation of the instrument.

12.21 Operator detection system

If an operator detection system is incorporated, it shall be verified that an information about operator presence or absence is logged into the logfile within one logging step after the operator came into contact with or has separated from the vibrating object.

The manufacturer shall include a description of the ODS in the instrument documentation, including recommended operational conditions.

12.22 Logging capabilities

The logging capability test shall run for a time period of 43 200 s (12 h). Part A of the PVEM shall be placed on a shaker and be exited 2 times for at least 300 s each. One test shall be performed at the beginning and one at the end of the 12 h test period. During the test the background noise should be minimized. The timestamps of the measurement shall match the time when the shaker was on/off.

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For whole-body measurements, the RMS magnitude of the shaker output shall be 1 m/s^2, for hand-arm measurements, the magnitude shall be 10 m/s^2.

With 1 s steps, there shall be 43 200 samples in the logging file of the 12 h test period. 600 samples shall correspond to the vibration magnitude.

12.23 Warning indication (mandatory warnings)

a) Information expressing whether the PVEM is ready for use.

It shall be verified that the PVEM is ready for use not later than the time at which the information for readiness is given by the PVEM.

b) Battery indicator.

Under reference environmental conditions, it shall be verified that a warning is signalled as soon as the battery capacity allows only 15 min to 30 min of remaining operation time.

After the warning indicator goes on, the PVEM shall still operate correctly for more than 15 min.

c) Overload indicator.

See 12.14.

12.24 Test report

Full details shall be given in the test report of the test configurations, instrument orientations, test conditions and test results, including the corresponding actual expanded uncertainties of measurement. The test report shall state that the complete instrument conforms to, or does not conform to, the specifications of this document.

The additional test information noted in IEC 61000-4-3:2006, Clause 8, shall be included. Any degradation in performance, loss of function or loss of data noted at the end of a series of electrostatic-discharge tests, AC power-frequency field tests or radio-frequency field tests shall be reported.

The test report shall also contain the following Information:

— the sample;

— a reference to this document, i.e ISO 8041-2:2021;

— any deviations from the procedure;

— any unusual features observed;

— the date of the test.

13 Periodic verification

13.1 General

Conformance with a specification of this document is demonstrated when the result of a measurement of a deviation from a design goal, extended by the actual expanded uncertainty of measurement of the testing laboratory, does not exceed the specified tolerance limits.

Uncertainties of measurement shall be determined in accordance with ISO/IEC Guide 98-3. The actual expanded uncertainties shall be calculated by the testing laboratory, with the coverage factor $k = 2$.

The verification test comprises calibration of the PVEM (which can be commissioned by the user of the instrument) by a testing laboratory (calibration laboratory). The verification test shall be conducted regularly.

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13.2 Testing requirements

The testing instruments used for verification tests which affect the uncertainty of test outputs shall hold valid calibrations, traceable to national or internationally recognized standards.

The frequency of the input signals shall be within ±0,2 % of the required value.

The magnitude of mechanical input signals shall be within ±3 % of the required value.

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

NOTE 1 For electrodynamic shakers acting below 20 Hz, the total distortion is likely to be greater than 5 %.

NOTE 2 For a mathematical definition of total distortion, see Formula (7).

The environmental conditions prevailing at the time of a test shall be within the following ranges:

— air temperature: 19 °C to 27 °C;

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

13.3 Test object

Test object is the PVEM with vibration transducer(s) forming a measurement chain for the measurement and display of band-limited and frequency-weighted acceleration according to the frequency weightings W_b, W_c, W_d, W_f, W_h, W_j, W_k or W_m.

NOTE The vibration transducer(s) can be a 3-axis (tri-axial) accelerometer or any 1-axis accelerometers.

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

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

13.4 Submission for testing

A vibration transducer of a type recommended for use with the PVEM shall be supplied with the instrument.

Vibration transducers other than that provided for verification testing may be used with the instrument, provided that the specification of those other vibration transducers are similar to that supplied for testing.

A field vibration calibrator can be supplied with the PVEM.

13.5 Preliminary inspection

The instrument, transducer and the field vibration calibrator (if supplied) shall be visually inspected. This inspection shall include inspections of the following:

— the transducer, cable and instrument case: these shall show no visible signs of physical damage;

— the connections between the transducer, cable and instrument and any other connections between components of the instrument: these shall be secure.

All controls shall be operated to ensure they are in working order.

13.6 Marking of the instrument and information in the instrument documentation

It shall be confirmed that the instrument is marked according to the specifications of Clause 9.

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Before conducting any tests, it shall be confirmed that the instrument documentation contains all the information required by Clause 10, appropriate to the facilities provided by the PVEM.

After completion of all tests, the information shall be reviewed to ensure that it is correct and within the appropriate tolerance limits.

13.7 Test procedure

For the following three typical applications, test procedures and parameters are specified which comprise only those tests of the instrument which are relevant to the application concerned:

a) vibration measurement chain for hand-arm vibration;

b) vibration measurement chain for whole-body vibration;

c) vibration measurement chain for low-frequency whole-body vibration.

NOTE At present, no verification test is specified for vibration meters measuring rotational whole-body vibration.

Each test procedure comprises the mechanical test of the combination of transducer and instrument, constituting a measurement chain which is set to the appropriate weighting filter(s). The validity of the verification test as stated on the calibration certificate is therefore limited to the application for which testing was performed.

Where necessary, the user can also commission testing of instrument configurations which differ from the typical configurations. The objective in all cases, however, is a calibration and test only of the measurement chain configuration which is actually used by the user.

The test procedure comprises mechanical calibration of the measurement chain with sinusoidal signals of defined amplitude and frequency. These test parameters are specified in 13.8. From the measurement results, the following is derived:

— the vibration sensitivity of the measurement chain;

— the amplitude linearity (or any deviation) at discrete input values;

— the frequency response at discrete frequencies.

13.8 Test parameters

13.8.1 Vibration measurement chain for hand-arm vibration

Frequency weighting:	W_h
Reference frequency:	500 rad/s (79,58 Hz)
Reference acceleration:	10,0 m/s^2
Unweighted input RMS values for mechanical amplitude linearity test:	5 m/s^2, 10,0 m/s^2, 100 m/s^2 at 79,58 Hz
Frequency range for frequency response:	10 Hz to 800 Hz at 10,0 m/s^2
Exact frequencies:	(10; 15,85; 79,43; 158,5; 794,3) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary, the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur.

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13.8.2 Vibration measurement chain for whole-body vibration

Frequency weightings:	W_b, W_c, W_d, W_j, W_k, W_m
Reference frequency:	100 rad/s (15,915 Hz)
Reference acceleration:	1,00 m/s^2
Unweighted input RMS values for mechanical amplitude linearity test:	0,1 m/s^2, 1,00 m/s^2, 10 m/s^2 at 15,915 Hz
Frequency range for frequency response:	2 Hz to 63 Hz at 1,00 m/s^2
Exact frequencies:	(1,995; 7,943; 15,85; 63,10) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary, the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur.

NOTE The frequencies given lie in that frequency range of the weighting curves where the tolerance band is ±1 dB (see ISO 8041-1:2017, Annex B). For those weighting curves where the tolerance band of ±1 dB extends to lower frequencies than 2 Hz, it is desirable to extend the frequency range below 2 Hz down to those frequencies where the tolerance band still is ±1 dB.

13.8.3 Vibration measurement chain low-frequency whole-body vibration

Frequency weighting:	W_f
Reference frequency:	2,5 rad/s (0,397 9 Hz)
Reference acceleration:	0,1 m/s^2
Unweighted input RMS values for mechanical amplitude linearity test:	0,01 m/s^2, 0,1 m/s^2, 1 m/s^2 at 0,397 9 Hz
Frequency range for frequency response:	0,2 Hz to 0,4 Hz at 0,1 m/s^2
Exact frequencies:	(0,199 5; 0,251 2; 0,397 9) Hz

In any case it shall be ensured that the input value is at least 20 dB above the noise floor. If necessary, the shaker acceleration may be increased. Distortion generated by the shaker shall be minimized. Overtravel of the shaker shall not occur. Some combinations of frequency and amplitude might exceed the displacement capability of the shaker, which is to be documented in the test report.

13.9 Conducting the test

Before conducting any tests, the instrument shall be given a power supply within the operating limits specified by the manufacturer.

The complete mechanical tests are performed by three separate tests:

— adjustment of vibration sensitivity at the reference frequency and reference acceleration;

— measurement of amplitude linearity response at the reference frequency;

— measurement of frequency response with a constant input vibration magnitude.

The transducer shall be connected in the best way to the mounting surface of the shaker. Care shall be taken to avoid that the fixing attachment affects the frequency response at high frequencies.

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A system for calibration by comparison in accordance with ISO 16063-21 should be used. The system shall be capable to adjust the defined amplitudes which shall be constant over the measurement time.

The measurements shall be performed using the complete measurement chain.

For the weighting filter selected, the vibration sensitivity of the PVEM at the reference frequency and reference acceleration shall be determined in each channel and then adjusted.

For the measurement of amplitude linearity response at the reference frequency within one measurement range, the amplitudes given in 13.8 shall be used. The values a_n at the display shall be documented. The linearity error which is the deviation, in %, at the values a_n minus the deviation at the reference acceleration a_{ref} shall be within the limits given in 5.7. The maximum expanded uncertainties of measurement are 5 %.

For the measurement of frequency response with a nearly constant input vibration magnitude, the frequencies given in 13.8 shall be used. The values a_n at the display shall be documented. The deviation from the design goals (see ISO 8041-1:2017, Annex B) shall be within the tolerances given in Table 5. The maximum expanded uncertainties of measurement are 5 %.

13.10 Test report

Full details shall be given in the test report of the test configurations, test conditions and test results. The test report shall state that the complete instrument has been verified, or has not been verified, as conforming to the specifications of this document as far as has been tested.

14 In-situ check

14.1 General

In-situ checks are intended for application in the field prior to and following a measurement or series of measurements. They act as a check of the instrument's basic calibration and functionality.

The instrument documentation shall include instructions for routine in-situ checks.

14.2 Preliminary inspection

The instrument documentation shall specify a visual inspection to confirm the physical integrity of the instrument. This inspection shall include inspections of the following:

— the accelerometer, cable and instrument case: these shall show no visible signs of physical damage;

— the connections between the accelerometer, cable and instrument and any other connections between components of the PVEM: these shall be secure.

14.3 Vibration sensitivity (field calibration)

It is recommended that an in-situ check of vibration sensitivity be performed. This shall then be described in the instrument documentation and include the following.

— A procedure for checking the mechanical vibration sensitivity of the PVEM, to be carried out at the reference vibration value on the reference measurement range and at the calibration check frequency using the specified field vibration calibrator.

For hand-arm vibration in-situ checks only, a check frequency of 159,15 Hz is permissible; the expected indication value can be derived from 5.6.

— An indication of the maximum change in vibration sensitivity likely to occur in normal use (i.e. the expected range of adjustment to vibration sensitivity; adjustments greater than this range can be an indication of instrument faults).

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— A recommended procedure for recording field calibration results; this shall include details of the date and time of test, settings of the PVEM and field vibration calibrator, the initial sensitivity and adjustments made to the sensitivity.

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Annex A
(informative)

Treatment of transient acceleration artefacts

A.1 Identifying and dealing with artefacts

Since the methods for identifying and dealing with, e.g. eliminating artefacts depend on the strategy and/or design of the PVEM, it is not possible to specify the processes and how to test them. The purpose of this annex is therefore to explain the basic principles and how they differ.

On the basis of these principles, the instrument manufacturer should explain to the user the processes utilized in the PVEM and provide guidance on how to check them for trouble-free function.

A.2 Principles of artefact treatment

Combining the processes based on the different principles is possible and may be selectable for the user.

a) Manual identification and treatment (rectification) of artefacts. By synchronizing the measurement signal with video recording throughout the measurement, it needs to be retroactively possible to depict and process the measurement signal in the time domain in different forms of application.

b) With the capture and processing of additional parameters, the artefacts are automatically identified and treated. For this, it may be necessary for the user to set boundary data or threshold values, e.g. on the basis of his experience or from prior tests, e.g. the threshold of contact forces on whole-body PVEM.

c) With algorithms of signal recognition and signal analysis, the artefacts are automatically identified and treated. For this, it may be necessary for the user to set boundary data or threshold values on the basis of his experience or from prior tests, e.g. certain frequency shares are identified due to DC shift or the exposed operator's own movements.

A.3 Treatment of artefacts

A.3.1 General

Since the causes and effects of transient acceleration artefacts differ, dedicated treatment methods and corrections are necessary for their elimination in order to achieve high-accuracy measurements.

Treatment methods are presented in A.3.2 to A.3.4 that can be supplemented with other methods. A.4 gives examples of optimum treatment methods for typical hand-arm artefacts while A.5 addresses treatment methods for typical whole-body artefacts. The PVEM should have a means of outputting the number and duration of identified and treated artefacts.

NOTE A display of the overall duration of identified and treated artefacts as a percentage of the total time can be helpful.

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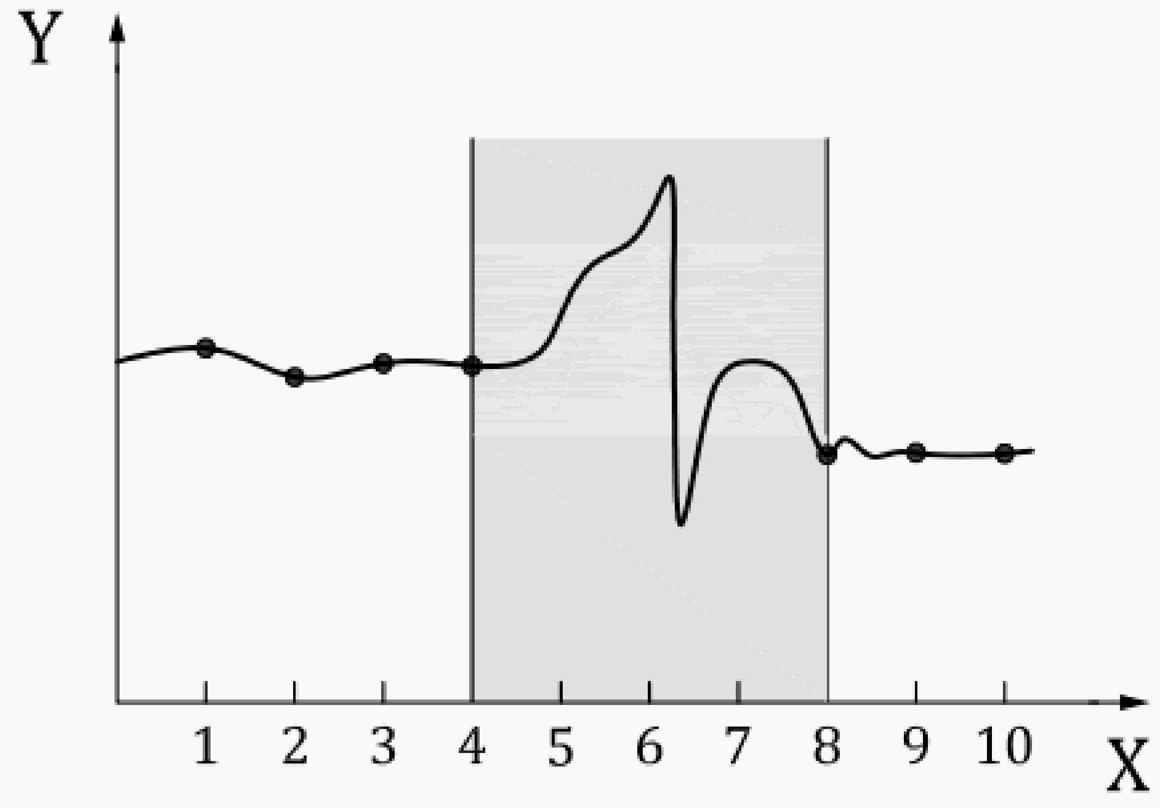
A.3.2 Cutting out the artefact



Key

X time in s

Y acceleration in m/s^2

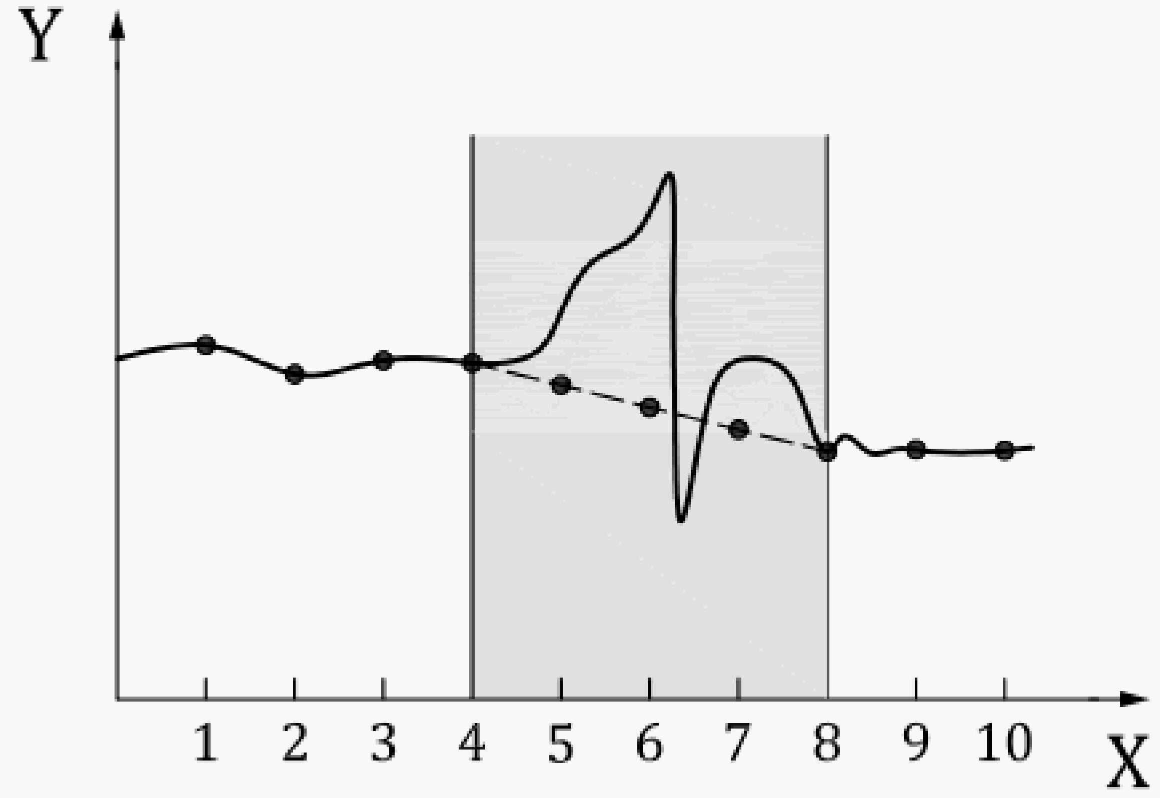
artefact duration

logged steps

Figure A.1 — Cutting out the artefact

Cutting out the artefact (see Figure A.1) reduces the measured exposure duration.

A.3.3 Linearizing the artefact



Key

X time in s

Y acceleration in m/s^2

artefact duration

logged steps

Figure A.2 — Linearizing the artefact

Linearization of the signal (see Figure A.2) between the start and end points of an artefact occurrence does not reduce the measured exposure duration.

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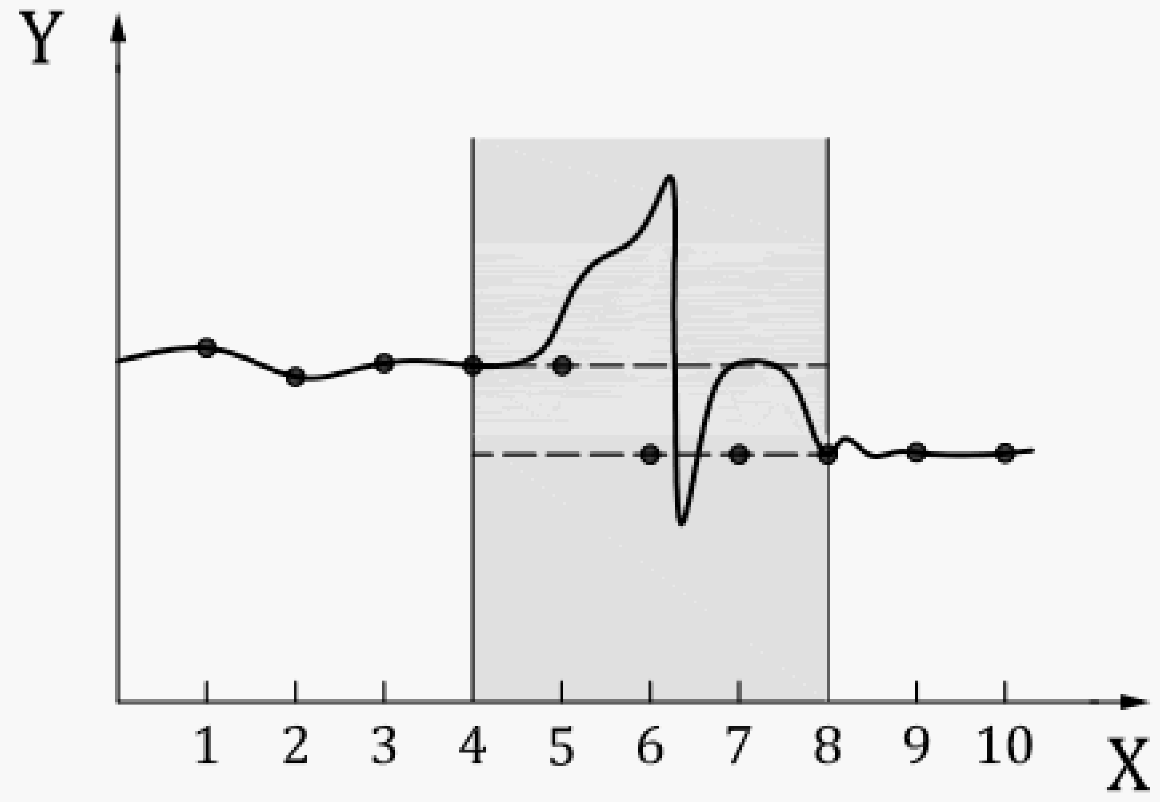
A.3.4 Substituting the artefact



Key

X time in s

Y acceleration in m/s^2

artefact duration

logged steps

Figure A.3 — Substituting the artefact

As a result of substituting (see Figure A.3), the signal for some part of the duration of the artefact is replaced by the signal preceding the start of the artefact occurrence and for the second part of the artefact duration by the following signal. This does not reduce the measured exposure duration.

A.4 Example of hand-arm artefact treatment

Table A.1 shows a list of hand-arm transient acceleration artefacts and treatment methods.

Table A.1 — List of hand-arm transient acceleration artefacts

ID	Description	Method
HA 1	Hand not at transmission point	A.3.2
HA 2	Operator's own movement with jolt	A.3.3
HA 3	Operator's own movement without jolt	A.3.4
HA 4	Short-lived contact resonance	A.3.3
HA 5	Other short-lived disturbance variables	A.3.4

A.5 Example of whole-body artefact treatment

Table A.2 shows a list of whole-body transient acceleration artefacts.

Table A.2 — List of whole-body transient acceleration artefacts

ID	Description	Addressed in
WB 1	Driver taking the seat	EN 14253
WB 2	Driver leaving the seat	EN 14253
WB 3	Driver not in contact with the seat because of bumps	EN 14253
WB 4	Driver jumping on the seat sensor	—

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Table A.2 *(continued)*

ID	Description	Addressed in
WB 5	Another driver/worker uses the vehicle/ movable equipment	—

WB 1 to WB 4 types of transient acceleration artefacts shall be rejected. The following strategy can be useful.

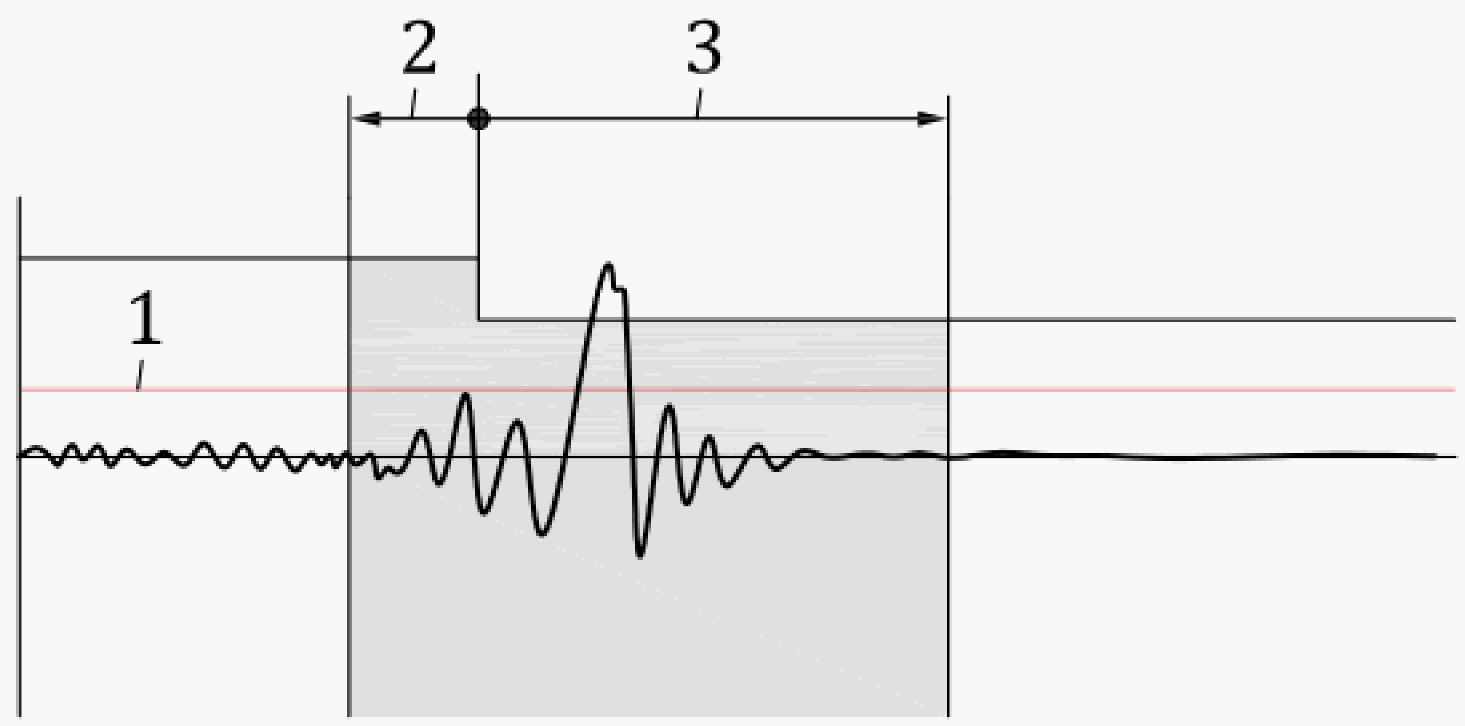
The RMS value of the weighed vibration signal is computed and stored for later analysis; this is considered as the vibration time history. Seat occupancy information is stored in parallel. Seat occupancy is considered ON if occupancy is detected. If it is not possible to detect occupancy from the stored RMS signal alone an additional system or transducer (seat sensor) shall be included to detect seat occupancy. This can be an additional force transducer, a spring-afflicted switch or a similar system. Table A.3 shows an occupancy detection-based artefact rejection strategy.

For steady results, the storage interval of the RMS value shall not be longer than 1 s.

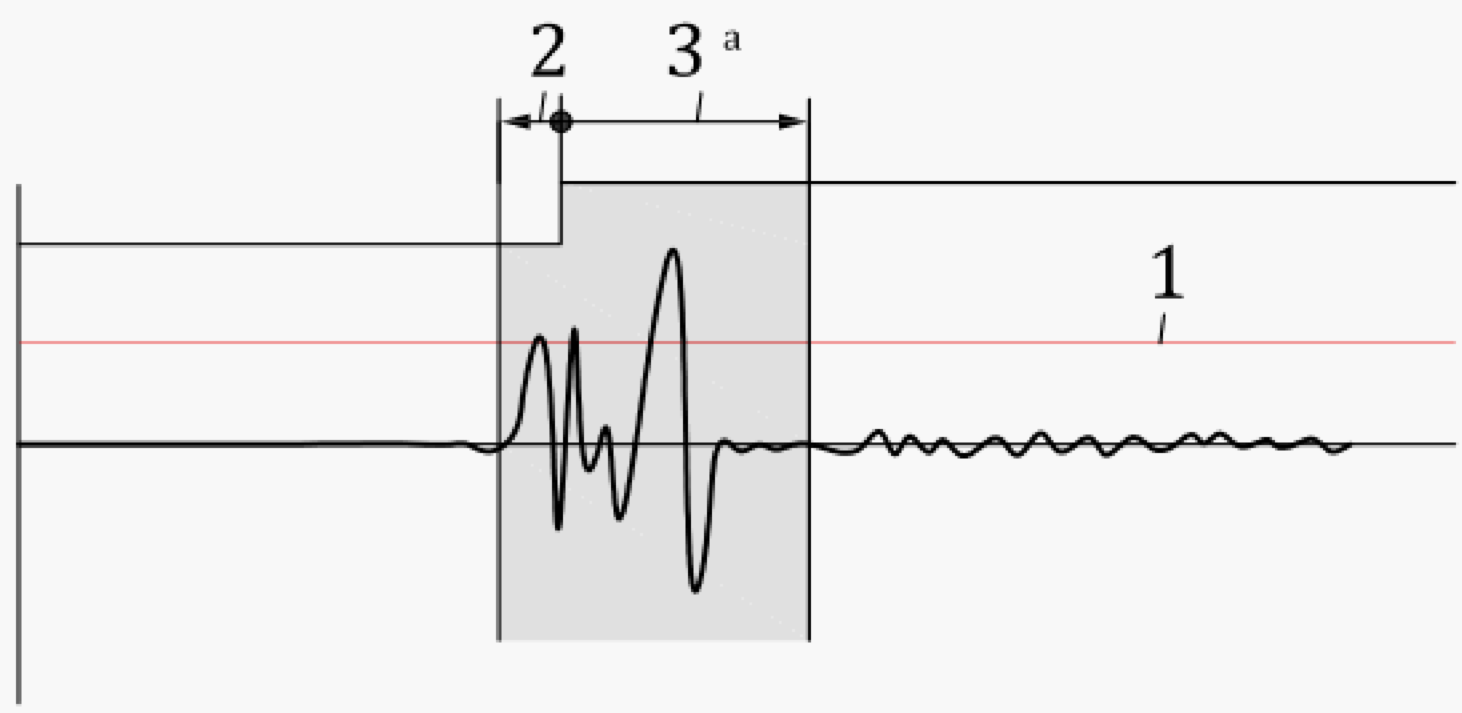
Table A.3 — Occupancy detection-based artefact rejection strategy

ID	Description	Counter measure
WB 1	Driver taking the seat	Some periods are discarded around the occupancy detection OFF-to-ON transitions
WB 2	Driver leaving the seat	Some periods are discarded around the occupancy detection ON-to-OFF transitions
WB 3	Driver not in contact with the seat because of bumps	Some periods are discarded around the occupancy detection both ON-to-OFF and OFF-to-ON transitions
WB 4	Driver jumping on the seat sensor	

Also it shall be possible to define a maximum duration for the artefact to be clear that the artefact is not influencing the result, see some examples in Figure A.4.



a) Driver is leaving the seat



b) Driver is taking the seat

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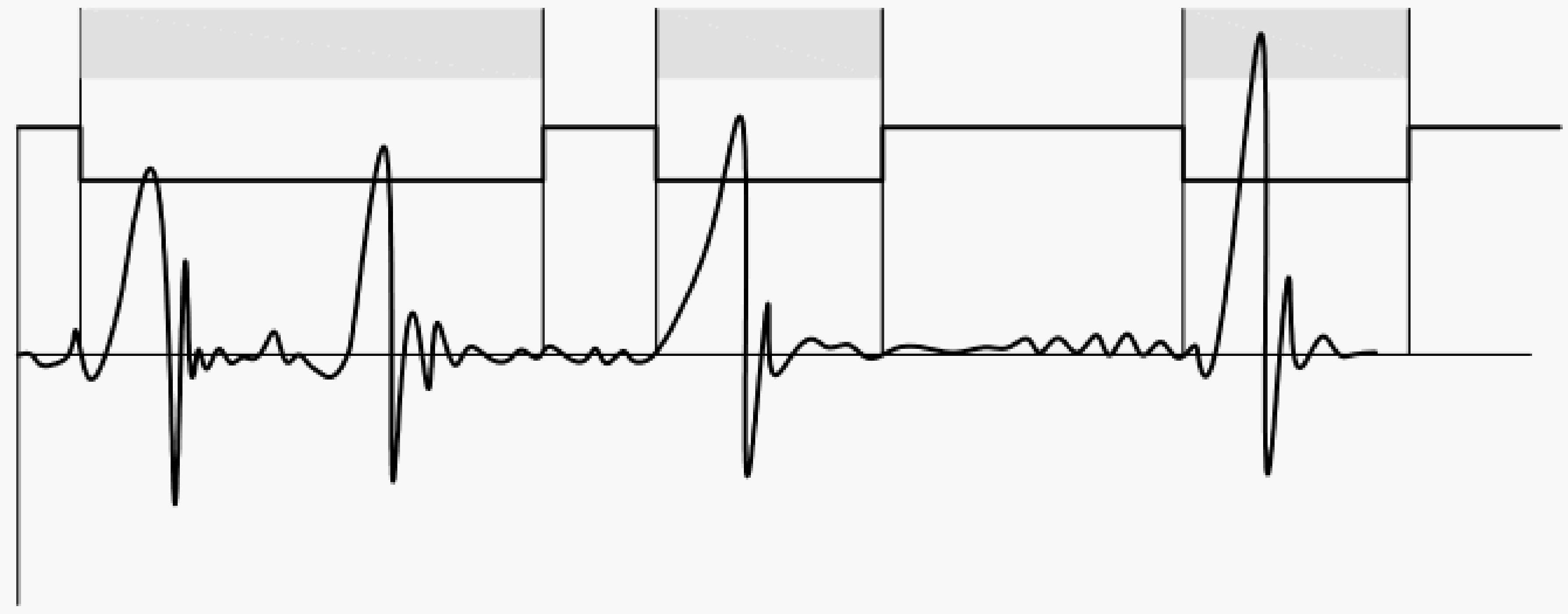

c) Bumps, jumping

Key

1 trigger value

2 pre-time

3 post-time

[grey box] not for evaluation due to artefacts

a = "max-time"

Figure A.4 — Example time histories of whole-body artefact treatment

Switch ON-OFF-ON for signal evaluation depends on max. and min. times between artefacts. The trigger value, pre- and post-times as well as max. and min. times between artefacts shall be defined.

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Annex B
(informative)

Influence of coupling force on hand-arm vibration evaluation

B.1 General

The accuracy of vibration measurements depends on several factors. However, the fundamental one is the coupling between the transducer and the vibrating surface. This can be evaluated by measurement of the coupling force between the transducer and the surface.

In the case of whole-body vibration, the coupling is assured by the body mass (at least for acceleration $< 10\ m/s^2$) and normally is not a problem. However, for the case of the very high impulse acceleration (e.g. on high-speed boats) a different approach is necessary.

Coupling forces between the hand-arm system and hand-held or hand-guided machines are very important factors for hand-transmitted vibration evaluation. ISO 5349-1 notes that the coupling of the hand to the vibrating surface can affect considerably the vibration magnitudes measured. Following ISO 15230-1, different couplings of the hand to a vibrating surface can affect the exposure to vibration.

Determination of the coupling force has two aspects:

a) Evaluation of the influence of the vibration on the human body,

b) determination of the uncertainty of the vibration exposure evaluation.

This document does not define guidance to evaluate the vibration exposure of the human body. For hand-arm vibration, the use of coupling force to adjust vibration exposure values is the subject of ISO/TR 15230-2.

The uncertainty of the vibration exposure evaluation is an essential parameter of the assessment of the health risk accuracy.

In all cases of hand-arm vibration measurements the following three transfer functions can be defined:

1. T_1 – transfer function between the transducer and the vibrating surface;

2. T_2 – transfer function along the handle between the transducer mounting point and the middle of the gripping zone of the hand;

3. T_3 – transfer function between the hand and the handle.

Figure B.1 illustrates these transfer functions.

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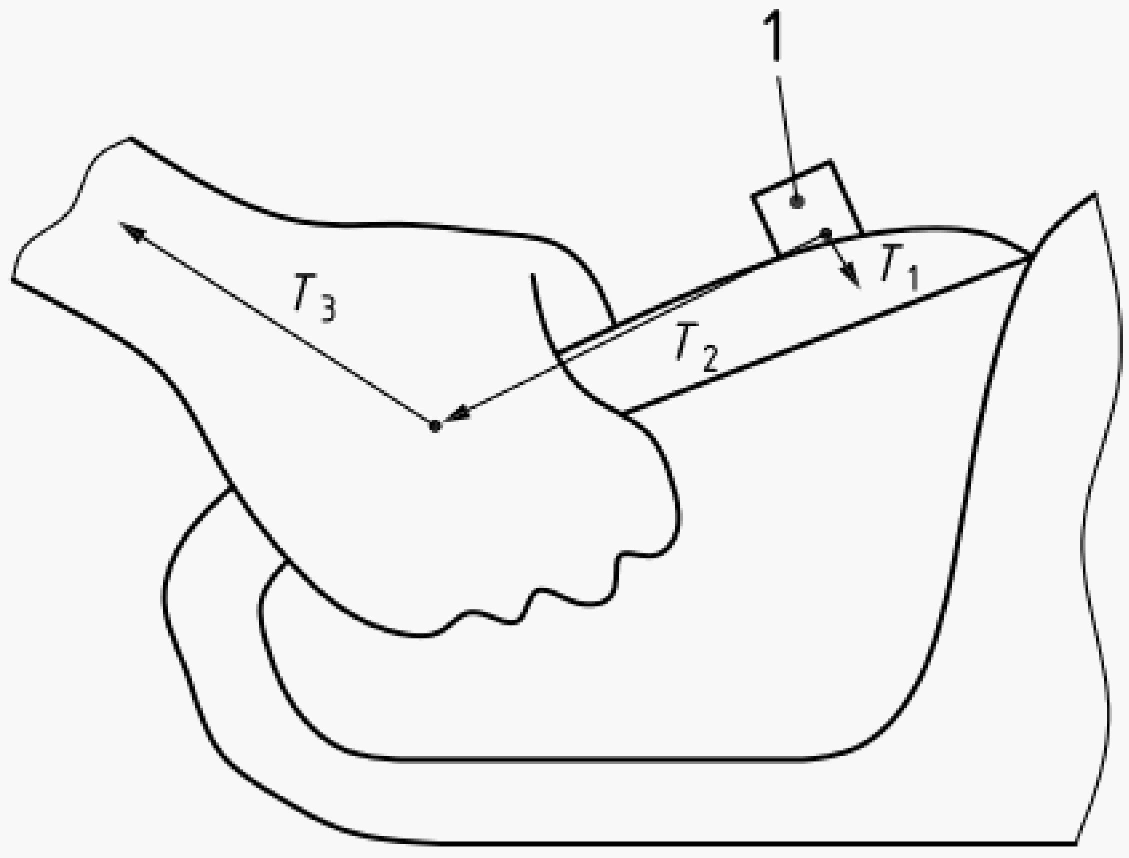
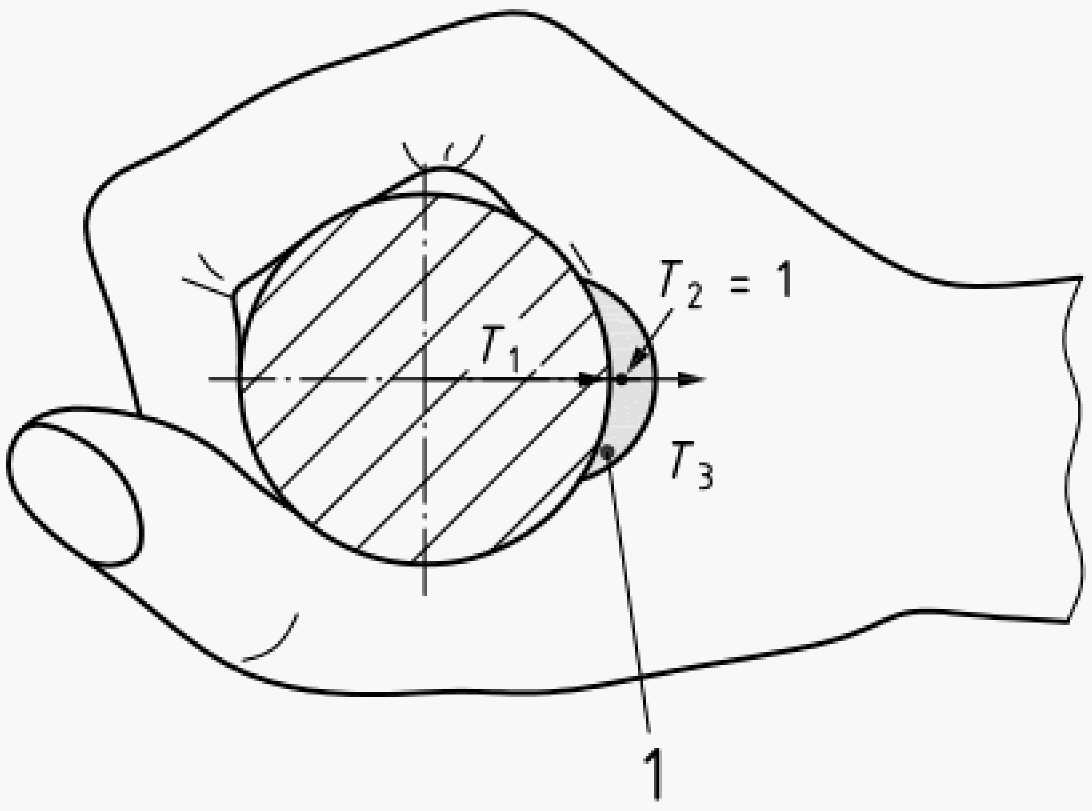


a) Measurement on the machine



b) Measurement on the human body

Key

1 transducer

Figure B.1 — Transfer functions between the hand-arm system and the machine handle

In order to obtain accurate measurement results the following condition should be met:

$$T_1 \times T_2 \times T_3 = T_{tot} = 1$$

or, at least, the total transfer function T_{tot} should be known (and compensated if different from 1). In particular T_3 has a high influence on the total measurement result.

In general when the transducer is mounted on the machine [as shown in Figure B.1 a)] and the coupling force is not measured, the transfer function T_3 is unknown, so the uncertainty of the evaluation is also unknown. To improve hand-arm vibration evaluation and reduce its uncertainty the coupling force should be measured and recorded.

B.2 Measurement of coupling forces

Coupling forces act between the hand and the vibrating surface: the push/pull force F_{pu} and the gripping force F_{gr}. The need for simultaneous measurement of both coupling force and vibration magnitude has

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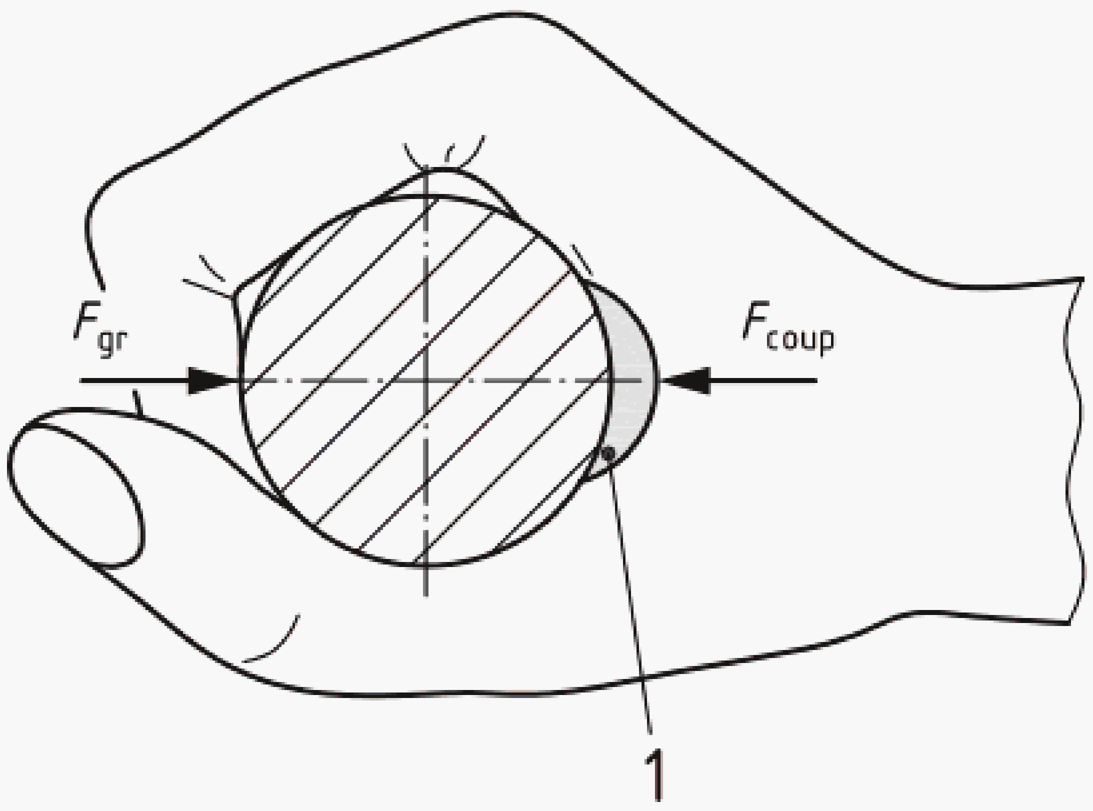
been recognized and is reflected in ISO 15230-1 that defines the coupling force F_{coup} equal to the sum of the gripping force and the push/pull force.

$$F_{coup} = F_{gr} + F_{pu}$$

Figure B.2 is an example illustration of the coupling force.



Key

1 transducer

Figure B.2 — Example illustration of coupling force as given by ISO 15230-1

Forces between the hand and the gripping zone should be measured and reported (see ISO 5349-1).

The frequency-weighted acceleration, a_{hw}, shall be measured in accordance with ISO 5349-2 using instrumentation that meets the requirements of ISO 8041-1 for hand-transmitted vibration instrumentation. Measurements shall be made at, or very close to, the gripping zone(s), i.e. where the operator grips the machine or vibrating element (see ISO/TR 15230-2).

Measurements of both hand-transmitted vibration and coupling force shall be made during the same or similar work activities. Where possible the measurements of coupling forces and frequency-weighted acceleration should be simultaneous, in order to account for possible dependencies between the two parameters (see ISO/TR 15230-2).

Small MEMS transducers and Force Sensitive Resistors (FSR) make it possible to locate the force transducer right next to the accelerometer. This solution allows the user to obtain simultaneously information about acceleration and coupling force. It can be demonstrated[[1]] that required accuracy of the acceleration measurement is maintained with such a solution, see Figure B.3.

Figure B.3 — Example of a hand-arm vibration adapter with triaxial MEMS transducer and force transducers installed

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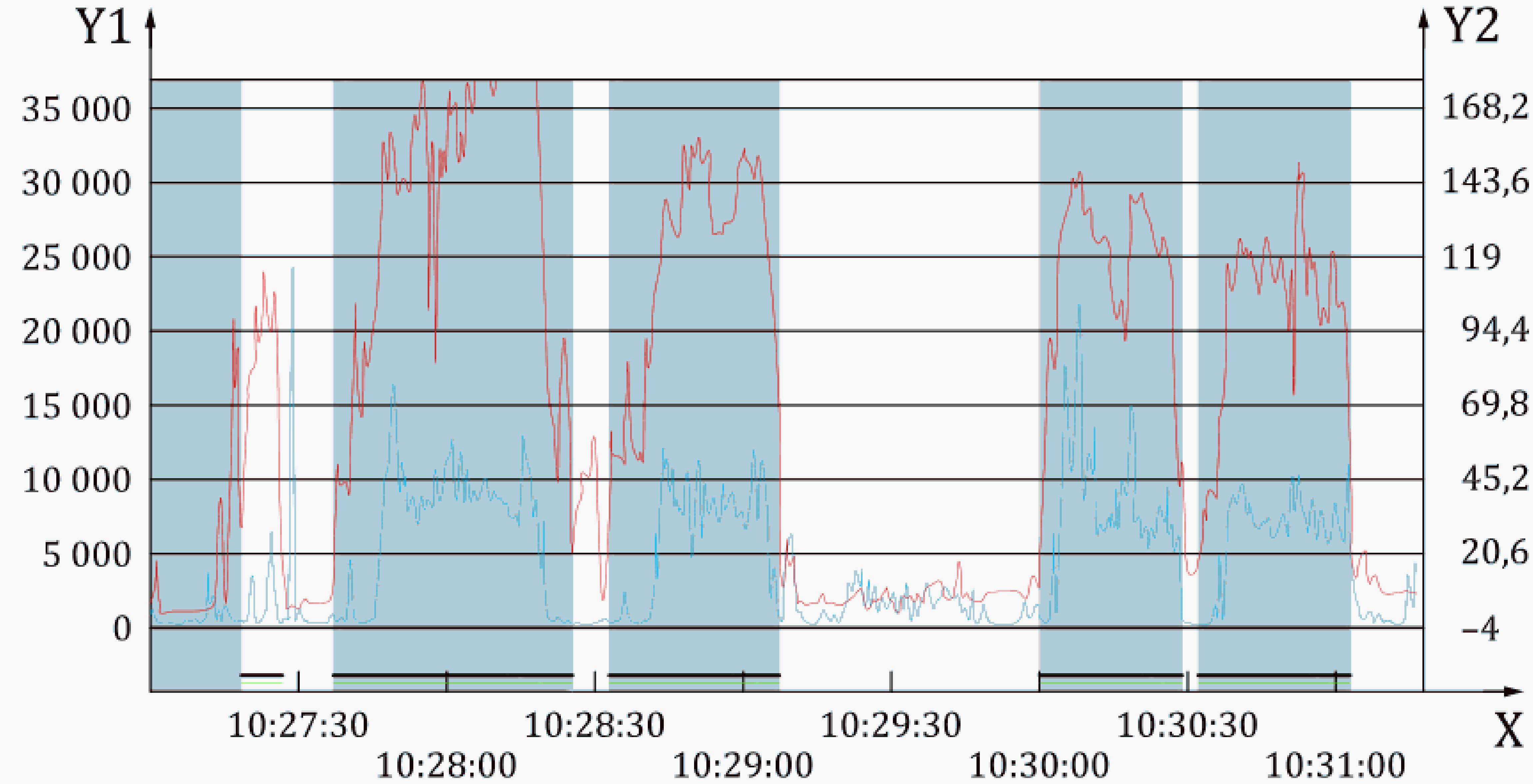
The logging of the coupling force enables to define periods of coupling of the hand with the machine or hand-held workpiece during use. When determining the vibration exposure, it is preferable to measure the vibration and the coupling parameters simultaneously. The vibration exposure should be based on time periods where the coupling force F_{coup} was above a given threshold (e.g. 20 N).

With this solution it is possible to perform continuous measurements through the whole working day which decreases the uncertainty of the sample limitation.

Logging of the coupling force with time is recommended in order to recognise atypical situations, e.g. negative feed forces during drilling. Alternatively, the frequency distribution of the measured coupling forces can be obtained in order to assess the validity of measurements and determine the mean feed force value (see ISO/TR 15230-2).

The time-history logging of coupling force values is important in determining the true exposure time by simple selection of the force threshold level and this is backed up by the analysis of spectrograms.

Measurements of very short duration (e.g. less than 8 s) are unlikely to be reliable, particularly in their evaluation of low-frequency components, and should be avoided where possible (see ISO 5349-2). In accordance with ISO 5349-2, short periods where the force values exceeded the threshold for less than 8 s should be excluded from the calculation, see Figure B.4.



Key

X time

Y1 acceleration in mm/s²

Y2 force in N

——— force avg.

——— a_{hv}

——— force level+

Figure B.4 — Example of filtering a_{hv} time-history with a force threshold of 20 N **for at least** 8 s

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Annex C
(informative)

Human interface

If part A of a PVEM device as specified in this document is not placed directly at the human interface, the results shall nevertheless be in conformance with the results of a transducer which is placed directly at the human interface with an appropiate correction factor. The tolerances as specified in this document shall be fulfilled in any case.

Calculations for correcting the measured results, using e.g. transfer functions or equivalent calculations from the original interface to the connection point (e.g. from the seat surface to the side of the seat) are allowed.

The coordinate system for a device not placed at the original interface shall be the same as for a transducer placed at the original human interface. If not, correction is necessary. The procedure of the correction is to be documented. It must be comprehensible for third parties. The manufacturer of the measuring device must describe the procedure in the operating instructions.

For the purposes of assessing transmitted vibration exposure to the hand-arm system, a PVEM device may be mounted remotely from the human interface in such a location as to not interfere with free operation of the machine or power tool. Transfer functions may be applied for the purposes of correcting attenuation or amplification between human interface and PVEM transducer. Such transfer functions would be required for each independent axis. A PVEM device mounted remotely from the human interface will be limited to monitoring machine frequencies within a specified range dictated by the PVEM manufacturer.

It should be noted that by mounting the transducer on the machine user rather than the machine handle factors likely to influence hand-transmitted vibration exposure outlined in ISO 5349-1:2001, Annex D, [a), e) and f)],could be captured by the PVEM and therefore a delta between measurements taken with ISO 8041-1 instruments and ISO 8041-2 remotely mounted transducers can be expected.

The manufacturer of the PVEM shall document the way to get the corrected results and provide testing procedures for verification, including tolerances and uncertanties.

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