TECHNICAL SPECIFICATION

# ISO/TS 15694

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# Mechanical vibration and shock — Measurement and evaluation of single shocks transmitted from hand-held and hand-guided machines to the hand-arm system

*Vibrations et chocs mécaniques — Mesurage et évaluation des chocs simples transmis par les machines portatives et guidées à la main au système main bras*

Reference number
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ISO/TS 15694 was prepared by the European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this document, read "...this European pre-Standard..." to mean "...this Technical Specification...".

# Contents

# Foreword

This document (CEN ISO/TS 15694:2004) has been prepared by Technical Committee CEN/TC 231 "Mechanical vibration and shock", the secretariat of which is held by DIN, in collaboration with Technical Committee ISO/TC 108 "Mechanical vibration and shock".

Annexes A, D and E are normative, Annexes B and C are informative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this CEN Technical Specification: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom

## Introduction

The effects of repeated shock-type excitations on the hand-arm system are not fully understood. A literature review ([5], [9] and [11]) shows that there is insufficient knowledge to establish whether the methods from EN ISO 5349-1 can be used for the assessment of health risks from shock-type loading of the hand and arm.

In spite of the lack of knowledge in this field, it is desirable to standardise methods for describing shock-type excitation from hand-held and hand-guided machinery. The purpose of this Technical Specification is to define methods

— for gathering consistent data on hand-transmitted single shocks under closely defined conditions and according to uniform criteria and

— for providing information on the shock emission of a given power tool, allowing an objective comparison of different power tools.

Power tools causing shock-type exposure are, for example, nailers, tackers, staplers and setting tools. Impact wrenches and nut runners are not included because it is not usually possible to trigger a single shock for these power tools.

Methods for the interpretation of the potential human effects of single shocks would be desirable but the lack of knowledge does not, at present, allow for the inclusion of such methods in a standard; in the future it is expected that these areas will be included.

The specification for instrumentation in ENV 28041 does not adequately describe the phase response, or the flat frequency response, for measurement of single shocks.

## 1 Scope

This Technical Specification specifies methods for measuring single shocks at the handle(s) of hand-held and hand-guided machinery characterised by a maximum strike rate below 5 Hz.

NOTE In order to describe the characteristics of single shocks, this Technical Specification defines quantities for the evaluation which go beyond those defined for hand-transmitted vibration in EN ISO 5349-1.

This Technical Specification also defines additional requirements for the measuring instrumentation which is necessary for the evaluation of shocks (see Annexes A, B, D and E).

The aim is to facilitate the gathering of emission and human exposure data in order to provide a basis for emission declaration and for the future development of exposure risk criteria. However, this Technical Specification does not provide methods for the interpretation of the potential human effects of single shocks.

This Technical Specification therefore is a basis for measurement and evaluation of emission of single shocks from hand-held and hand-guided machinery but does not cover the evaluation of human exposure.

## 2 Normative references

This Technical Specification incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this Technical Specification only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 1033, *Hand-arm vibration — Laboratory measurement of vibration at the grip surface of hand-guided machinery — General*

ENV 28041, *Human response to vibration — Measuring instrumentation (ISO 8041:1990)*

EN ISO 5349-1:2001, *Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 1: General requirements (ISO 5349-1:2001)*

EN ISO 5349-2, *Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 2: Practical guidance for measurement at the workplace (ISO 5349-2:2001)*

CEN ISO/TS 8662-11, *Hand-held portable power tools — Measurement of vibrations at the handle — Part 11: Fastener driving tools (nailers) (ISO 8662-11:1999 + Amd. 1:2001)*

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

## 3 Terms and definitions

For the purposes of this Technical Specification, the symbols given in EN ISO 5349-1 and the terms and definitions given in EN ISO 5349-2 and the following apply.

**3.1**
**single shock**
short burst of acceleration

NOTE 1 The acceleration time history of a single shock includes a rise to a peak value (see 4.7), followed by a decay of the acceleration envelope.

NOTE 2 In principle a single shock could also be defined by other physical quantities, for example force or mechanical power transmitted to the hand-arm system. Due to practical measurement considerations, however, the restricted definition in terms of acceleration is used (see also Annex C).

EXAMPLE Power tools causing single shocks or single-shock vibration are nailers, tackers, staplers, setting tools, etc. These power tools produce a burst of high acceleration with short duration (e.g. 10 ms). The period between two shocks is much longer than the shock itself (e.g. greater than 200 ms).

**3.2**
**single-shock vibration**
series of single shocks separated by periods of zero acceleration

EXAMPLE See example in 3.1.

**3.3**
**repetition time**
$T_{rep}$
time interval between two consecutive single shocks

**3.4**
**strike rate**
$f_0$
for constant repetition time $T_{rep}$, the reciprocal of the repetition time, i.e. $f_0 = 1/T_{rep}$

**3.5**
**flat$_h$**
designation for unweighted acceleration which is band-limited as specified in 4.2 and Annex D

# 4 Parameters for describing single shocks

## 4.1 Acceleration

The basic quantity for describing single shocks is the acceleration $a(t)$. It is the basis of all parameters used in this Technical Specification.

NOTE For use of the vibration velocity to describe single shocks, see Annex C.

## 4.2 Flat$_h$-weighted acceleration

The flat$_h$-weighted acceleration $a_{hF}(t)$ is the band-limited acceleration in the frequency band from 6,3 Hz to 1250 Hz. The filter for the flat$_h$ weighting is specified in Annex D.

NOTE 1 This frequency band corresponds to the octave bands from 8 Hz to 1000 Hz. In some cases a wider pass band is required; variations should then be reported with the measurement values.

NOTE 2 The flat$_h$ weighting differs from the flat responses often provided on measuring instrumentation by a clearly defined frequency band and phase response.

NOTE 3 Unweighted acceleration in this Technical Specification means band-limited acceleration in the frequency band with a low-pass corner frequency greater than 1250 Hz.

## 4.3 Root-mean-square value of flat$_h$-weighted acceleration

Using the specification in 4.2 the root-mean-square (r.m.s.) value of $a_{hF}(t)$ in a time interval $T$ is given by

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

It describes the energy-equivalent average value of the signal. A prescribed fixed integration time of $T = 3$ s allows comparison of various measurement results and helps the tool operator to achieve reproducibility.

Experience shows that $T = 3\,\text{s}$ is a good compromise between the reaction time of the operator and the requirement for shortest practicable integration time. In order to increase the confidence level of the results it is advisable to take the average of this quantity over a series of single shocks (see 6.3).

### 4.4 Running root-mean-square value of flat$_h$-weighted acceleration

Using the specification in 4.2 the running root-mean-square value of $a_{hF}(t)$ at time of observation, $t$, is given by

$$a_{hF,RRMS,\tau}(t) = \sqrt{\frac{1}{\tau}\int_0^t a_{hF}^2(\xi)\,\mathrm{e}^{-\frac{t-\xi}{\tau}}\,\mathrm{d}\xi} \qquad (2)$$

where

$t$ is the time of observation (actual time)

$\xi$ is the integration variable

$\tau$ is a time constant which is to be specified. A time constant $\tau$ = 0,125 s is preferred.

In order to increase the confidence level of the results it is advisable to take the average of this quantity over a series of single shocks (see 6.3).

NOTE 1 The exponential averaging function describes the behaviour of many natural processes. It can be generated by very simple analogue or digital signal processing. The true running r.m.s. acceleration value, obtained by linear integration over a running time interval of fixed length, looks simpler mathematically but would, in reality, be more difficult to achieve with analogue instrumentation without any advantage.

NOTE 2 Other International Standards prefer the linear averaging for the running root-mean-square value, which is defined as follows:

$$a_{hF,RRMS,\tau}(t) = \sqrt{\frac{1}{\tau}\int_0^t a_{hF}^2(\xi)\,\mathrm{d}\xi}$$

### 4.5 Root-mean-quad value of flat$_h$-weighted acceleration

Using the specification in 4.2 the root-mean-quad (r.m.q.) value of $a_{hF}(t)$ in a time interval $T$ is given by

$$a_{hF,RMQ,T} = \sqrt[4]{\frac{1}{T}\int_0^T a_{hF}^4(t)\,\mathrm{d}t} \qquad (3)$$

As with the root-mean-square value in 4.3 it describes an average value of the signal. However, with the r.m.q. average the influence of the higher magnitudes is stronger than with the r.m.s. A prescribed fixed integration time of $T = 3\,\text{s}$ allows comparison of various measurement results and helps the tool operator to achieve reproducibility. Experience shows that $T = 3\,\text{s}$ is a good compromise between the reaction time of the operator and the requirement for shortest practicable integration time. In order to increase the confidence level of the results it is advisable to take the average of this quantity over a series of single shocks (see 6.3).

### 4.6 Maximum transient vibration value of flat$_h$-weighted acceleration

Using the specifications in 4.4 the maximum transient vibration value (MTVV) in the time interval $T$ is the highest magnitude of $a_{hF,RRMS,\tau}(t)$ as given by

$$a_{hF,MTVV,\tau} = \max_{0 \le t \le T} \left\{ a_{hF,RRMS,\tau}(t) \right\} \quad (4)$$

In order to increase the confidence level of the results it is advisable to take the 50$^{th}$ percentile of this quantity over a series of single shocks.

## 4.7 Peak value of flat$_h$-weighted acceleration

For any specified time interval $0 \le t \le T$, the peak value (PV) of $a_{hF}(t)$ is the maximum absolute instantaneous value, as given by

$$a_{hF,PV} = \max_{0 \le t \le T} \left\{ \left| a_{hF}(t) \right| \right\} \quad (5)$$

This quantity is used to describe the top level of the signal. In order to increase the confidence level of the results it is advisable to take the 50$^{th}$ percentile of this quantity over a series of single shocks.

## 4.8 Crest factor of flat$_h$-weighted acceleration

Using the quantities in 4.3 and 4.7 the crest factor of the flat$_h$-weighted acceleration, $CF_h$, is obtained by dividing the peak value of flat$_h$-weighted acceleration by the root-mean-square value of the flat$_h$-weighted acceleration measured in the same time period $T$:

$$CF_h = \frac{a_{hF,PV}}{a_{hF,RMS,T}} \quad (6)$$

This quantity combines the peak value of the signal with the energy-equivalent r.m.s. value and therefore describes the impulsiveness of the flat$_h$-weighted signal.

## 4.9 Shock content quotient of flat$_h$-weighted acceleration

Using the quantities in 4.3 and 4.5 the shock content quotient of the flat$_h$-weighted acceleration, $SC_h$, is obtained by dividing the root-mean-quad value of the flat$_h$-weighted acceleration by the root-mean-square value of the flat$_h$-weighted acceleration measured in the same time period $T$:

$$SC_h = \frac{a_{hF,RMQ,T}}{a_{hF,RMS,T}} \quad (7)$$

This quantity also describes the impulsiveness of the signal.

## 4.10 W$_h$-weighted acceleration

The frequency weighting characteristic W$_h$, used for the measurement and evaluation of hand-transmitted vibration, is defined in EN ISO 5349-1 and is precisely specified in Annex E. W$_h$-weighted acceleration is denoted by $a_{hw}(t)$.

NOTE 1 $a_{hw}(t)$ may be derived from $a_{hF}(t)$ (see 4.2) by applying an acceleration-velocity transition function (a-v-transition) which converts acceleration into velocity for frequencies above 16 Hz.

NOTE 2 Although the frequency weighting in EN ISO 5349-1 was originally defined in order to assess periodic and random or non-periodic vibration, EN ISO 5349-1:2001 states that it may provisionally "also be applied to repeated shock type excitation (impact)." In addition, use of the W$_h$ frequency weighting allows comparison with existing data. Furthermore, measurements of parameters based on $a_{hw}(t)$ can be more reproducible, because problematic higher-frequency components are attenuated.

The order of presentation chosen in this Technical Specification (flat$_h$ weighting, followed by W$_h$ weighting) does not imply that the former is preferred.

### 4.11 Root-mean-square value of $W_h$-weighted acceleration

Using the specification in 4.10 the root-mean-square value of $a_{hw}(t)$ in a time interval $T$ is given by

$$a_{hw,RMS,T} = \sqrt{\frac{1}{T}\int_0^T a_{hw}^2(t)\,\mathrm{d}t} \quad (8)$$

It describes the energy-equivalent average value of the signal. A prescribed fixed integration time of $T = 3\,\mathrm{s}$ allows comparison of various measurement results and helps the tool operator to achieve reproducibility. Experience shows that $T = 3\,\mathrm{s}$ is a good compromise between the reaction time of the operator and the requirement for shortest practicable integration time. In order to increase the confidence level of the results it is advisable to take the average of this quantity over a series of single shocks (see 6.3).

### 4.12 Root-mean-quad value of $W_h$-weighted acceleration

Using the specification in 4.10 the root-mean-quad value of $a_{hw}(t)$ in a time interval $T$ is given by

$$a_{hw,RMQ,T} = \sqrt[4]{\frac{1}{T}\int_0^T a_{hw}^4(t)\,\mathrm{d}t} \quad (9)$$

As with the root-mean-square value in 4.11 it describes an average value of the signal. However, with the r.m.q. average the influence of the higher magnitudes is stronger than with the r.m.s. A prescribed fixed integration time of $T = 3\,\mathrm{s}$ allows comparison of various measurement results and helps the tool operator to achieve reproducibility. Experience shows that $T = 3\,\mathrm{s}$ is a good compromise between the reaction time of the operator and the requirement for shortest practicable integration time. In order to increase the confidence level of the results it is advisable to take the average of this quantity over a series of single shocks (see 6.3).

### 4.13 Shock content quotient of $W_h$-weighted acceleration

Using the specifications in 4.11 and 4.12 the shock content quotient of $a_{hw}(t)$ is given by the quotient of the root-mean-quad and the root-mean-square values measured in the same time period *T*:

$$SC_{hw} = \frac{a_{hw,RMQ,T}}{a_{hw,RMS,T}} \quad (10)$$

This quantity describes the impulsiveness of the $W_h$ frequency-weighted signal.

## 5 Measuring instrumentation

The root-mean-square value of the $\text{flat}_h$-weighted acceleration and $W_h$-weighted acceleration, defined in 4.3 and 4.11, with integration time $T = 3\,\mathrm{s}$, can be determined with measuring instrumentation in accordance with ENV 28041 as long as the frequency band of the flat response of the instrumentation is as defined in 4.2. For the evaluation of all other parameters, the acceleration has to be measured with instrumentation which conforms to the requirements of Annex A (for digital measuring instrumentation, see also Annex B).

NOTE The requirements of Annex A exceed those specified in ENV 28041.

In practice, it will be difficult to satisfy the requirements of all the annexes if mechanical filters are used.

# 6 Measurement procedure

## 6.1 Attaching accelerometers

For the measurement of the $flat_h$-weighted quantities, in particular the peak values, the accelerometer shall be rigidly fixed to give a flat frequency response in the frequency range 6,3 Hz to 1250 Hz. The guidelines for mechanical mounting of accelerometers as given in ISO 5348 shall be followed.

To take into account the effects of elastic grips, the acceleration shall be measured at the interface between the power tool and the operator's hand by means of a suitable adaptor. In this case, special attention shall be paid to measurement problems due to contact resonance.

For the measurement of $W_h$-weighted acceleration only, the guidance on accelerometer mounting given in EN ISO 5349-2 should be followed.

If required, mechanical filters may be used when measuring the root-mean-square acceleration ($flat_h$-weighted or $W_h$-weighted). However, when determining peak values, r.m.q. values or parameters derived from them, the use of mechanical filters may produce errors and is not recommended.

NOTE 1 Some cements, such as those used for wire strain gauges, serve not just the purpose of fixation, but are also designed to withstand high dynamic loads.

NOTE 2 In the case of plastic shell handles, the coupled mass of the accelerometer, including the adaptor, should be as small and low in mass as possible. It is recommended that the mass is less than 12 g.

NOTE 3 The effect of accelerometer coupling on the measurement results can be determined by using laser vibrometers. For general use, however, the application of laser vibrometers may be considered costly or impracticable.

## 6.2 Orientation of accelerometers

The accelerometers shall be oriented in the main excitation direction. In cases in which the main excitation direction is not obvious it shall be determined by measurement in three orthogonal axes.

NOTE Inaccurate orientation yields incorrect results due to the transversal sensitivity of the accelerometer. Sensitivities determined with cyclic signals are not valid for this application.

## 6.3 Working procedure

To distinguish the shock caused by the operating procedure from that caused by the power tool, it is necessary to organise the procedure in a suitable way minimising the influence of the tool operator.

It is allowed to conduct the measurement with a series of $n_{sh}$ (e.g. $n_{sh} = 10$) individual shocks or with single shocks. In cases where the repetition time can be varied, a repetition time of $T_{rep} = 3\ \mathrm{s}$ shall be used. When measuring with single shocks a measurement period of $T = 3\ \mathrm{s}$ shall be used.

In cases where the measurement is conducted with a series of shocks, the root-mean-square and the root-mean-quad parameters may be determined as the arithmetic average of the series.

# 7 Measurement report

The report shall include relevant information as prescribed by EN 1033, EN ISO 5349-1 or CEN ISO/TS 8662-11. Furthermore, the following items shall be documented:

a) identification of the main excitation direction;

b) exact description of the coupling of the accelerometer;

c) mass of the accelerometers and the accessories (mechanical filters, adaptors, etc.);

d) number of shocks during the measurement ($n_{sh}$);

e) root-mean-square value of flat$_h$-weighted acceleration with $T = 3$ s ($a_{hF,RMS,3}$);

f) root-mean-square value of W$_h$-weighted acceleration with $T = 3$ s ($a_{hw,RMS,3}$).

The following information is optional:

g) crest factor of flat$_h$-weighted acceleration with $T = 3$ s ($CF_h$);

h) peak value of flat$_h$-weighted acceleration ($a_{hF,PV}$);

i) shock content quotient of flat$_h$-weighted acceleration with $T = 3$ s ($SC_h$);

j) shock content quotient of W$_h$-weighted acceleration with $T = 3$ s ($SC_{hw}$);

k) maximum transient vibration value of flat$_h$-weighted acceleration and the time constant $\tau$ ($a_{hF,MTVV,\tau}$ and $\tau$);

l) root-mean-quad value of flat$_h$-weighted acceleration with $T = 3$ s ($a_{hF,RMQ,3}$);

m) root-mean-quad value of W$_h$-weighted acceleration with $T = 3$ s ($a_{hw,RMQ,3}$).

NOTE 1 The list of parameters above is not exhaustive. For research purposes, it may be necessary to add other parameters.

NOTE 2 It is good practice to record the whole acceleration time history to allow for future re-analysis.

# Annex A
(normative)

# Requirements and test methods for the measuring instrumentation

## A.1 General

If the time history or the peak value of a signal is to be measured it is necessary to specify (and test) the phase frequency response of the instrument in addition to the amplitude frequency response. Since this is missing from the current standard for human vibration instrumentation (ENV 28041) such specifications and test procedures are given in this annex.

The band-limiting filter shall be composed of a low-pass and a high-pass filter of second order with Butterworth characteristic. The cut-off frequencies shall be 6,3 Hz and 1250 Hz for the high-pass and low-pass filters, respectively.

To prescribe the requirements three frequency ranges are introduced:

**Range 1**: Interior frequency range from two third-octaves above the lower frequency band limit up to two third-octaves below the upper frequency band limit (i.e. 10 Hz to 800 Hz), with the exception of the reference frequency (80 Hz)

**Range 2**: Upper and lower border ranges spanning two third-octave bands either side of the frequency band limits (i.e. 4 Hz to 10 Hz and 800 Hz to 2000 Hz)

**Range 3**: Ranges outside range 1 and range 2.

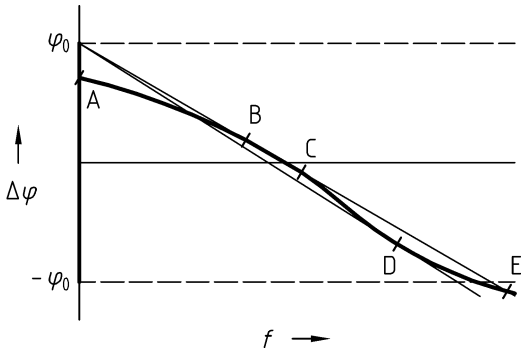
## A.2 Phase frequency response

It is not feasible in practice to create an ideal linear phase frequency response. For this reason, the following criteria are provided (for a test method of the phase frequency response of digital measuring instrumentation, see Annex B).

The requirements to limit the peak value deviation $\Delta PV_{\max}$ are illustrated in Figure A.1. The difference $\Delta\varphi$ between the actual phase angle $\varphi_{act}$ and the nominal phase angle $\varphi_{nom}$ shall fulfil the following requirements. The values for the characteristic values $\varphi_0$ and the maximum peak value deviation $\Delta PV_{\max}$ are given in Table A.1. The interpretation of the criteria is as follows:

a) If the deviation $\Delta\varphi = \varphi_{act} - \varphi_{nom}$ is drawn over the linear frequency axis, then all tangents at the curve shall intersect with the $\Delta\varphi$-axis between $-\varphi_0$ and $+\varphi_0$ (tangent criterion a).

b) If the deviation $\Delta\varphi = \varphi_{act} - \varphi_{nom}$ is drawn over the logarithmic frequency axis, then the maximum distance of the tangents to the curve shall not amount to more than $\pm\varphi_0$ off the frequency axis at a frequency of 1,44 octaves (1/e times) underneath its point of contact (tangent criterion b).

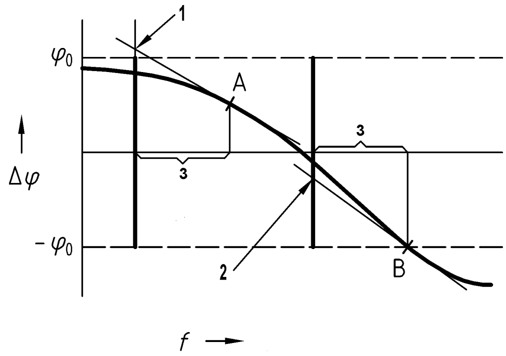



A–B, D–E: tangent criterion a fulfilled

B–C: range of maximum use of tolerances

C–D: tangent criterion a not fulfilled, as the curve is too steep (but to a slight extent only, when the ratio of frequencies at points E and C is < 3:1)

**a) For linear frequency axis**




**Key**

1 In A, the tangent criterion b is not fulfilled

2 In B, the tangent criterion b is fulfilled

3 1,44 octaves

*f* logarithmic

**b) For logarithmic frequency axis**

**Figure A.1 — Illustration of tangent criteria for limits of permissible error of the phase response**

The prerequisites for such testing of the phase response are:

— There shall be a way to check the signal directly before peak value detection and

— the detector shall have no influence upon the measurement deviation.

NOTE The phase frequency response is indirectly determined by the amplitude frequency response through the complex frequency response function, which in turn depends on operation- and application-related prerequisites. A phase shift angle which is proportional to the frequency (constant group delay) would not be justified either by application or cost.

When testing the phase response in accordance with the above-mentioned criteria, the frequency shall be varied in steps of maximum one third-octave, whereby the tangents pass into secants through neighbouring points of the curve.

Alternatively, other specifications could provide for an implicit test of the phase response by the nominal peak values theoretically to be expected after the complex nominal frequency response and the limits of permissible error have been given for certain mechanical test signals having a harmonic content.

**Table A.1 — Characteristic values $\varphi_0$ for the tangent criteria a and b and the approximated maximum peak value deviation $\Delta PV_{max}$**

| | Characteristic value $\varphi_0$ | Maximum peak value deviation $\Delta PV_{max}$ |
|---|---|---|
| Range 1 | 6° | ± 5 % |
| Range 2 | 12° | ± 10 % |
| Range 3 | not prescribed | not prescribed |

## A.3 Amplitude frequency response

Starting from the reference frequency for which the error by definition is zero, the actual and the nominal amplitude frequency responses shall correspond within a given error limit as follows:

$$1-\frac{G_u}{100\ \%}\leq\frac{R(f)}{R(f_r)}\cdot\frac{M(f_r)}{M(f)}\cdot\frac{H(f_r)}{H(f)}\leq 1+\frac{G_o}{100\ \%}\qquad\text{(A.1)}$$

where

$f$ is the frequency

$f_r$ is the reference frequency

$M$ is the root-mean-square value of the mechanical input

$R$ is the root-mean-square value of the reaction of the instrumentation

$H$ is the nominal amplitude frequency response

$G_u$ and $G_o$ are the lower and upper limits, respectively, of error from Table A.2.

**Table A.2 — Limit of error for the amplitude frequency response**

| | Limit of error | |
|---|---|---|
| | $G_o$ | $G_u$ |
| Reference frequency | 0 | 0 |
| Range 1 | 5 % | 5 % |
| Range 2 | 10 % | 10 % |
| Range 3 | 20 % | 100 % |
| NOTE In the ranges, where the band-limiting is active, the errors have less influence, therefore the limits of error in range 3 are relatively wide. | | |

# Annex B
(informative)

# Recommendations and test methods for a digital measuring instrumentation

## B.1 General

Generally the requirements of ENV 28041 apply with the following additions: In order to measure peak values (PV) or fourth power based quantities (r.m.q.) uniformly it is necessary to standardize the frequency response of the phase shift (phase frequency response) of the measuring instrumentation in addition to its amplitude frequency response. The same applies in principal for the measurement of maximum running root-mean-square values (MTVV) with short time constants.

## B.2 Phase frequency response

The design goal of the phase frequency response is determined implicitly by the complex transfer function defined in EN ISO 5349-1. The design goal for $W_h$ frequency-weighted quantities is given by equation (B.1) explicitly. For $flat_h$-weighted quantities (i.e. band limitation only, see 4.2), the last two terms should be dropped.

$$\varphi(f) = \arctan\left(\frac{\frac{f_1}{f}\cdot\sqrt{2}}{1-\left(\frac{f_1}{f}\right)^2}\right) - \arctan\left(\frac{\frac{f}{f_2}\cdot\sqrt{2}}{1-\left(\frac{f}{f_2}\right)^2}\right) + \arctan\left(\frac{f}{f_3}\right) - \arctan\left(\frac{\frac{f}{f_3\cdot Q_2}}{1-\left(\frac{f}{f_3}\right)^2}\right) \quad \text{(B.1)}$$

where $f_1$ to $f_3$ and $Q_2$ are as defined in EN ISO 5349-1.

NOTE 1 A measuring instrument (including the transducer) designed to fulfil the requirements for the amplitude frequency response with a minimum of analogue circuitry will automatically have the correct phase frequency response. In the case of digital filters this phase frequency response can be approximated. It is not appropriate to demand a linear phase response.

For measuring instrumentation under test, the phase frequency response deviation $\Delta\varphi(f)$ from the design goal $\varphi(f)$ shall be determined in frequency intervals not larger than one third-octave. For each discrete frequency $f_n$, the phase deviation $\Delta\varphi(f_n)$ is converted by equation (B.2) into a characteristic phase deviation $\Delta\varphi_0(f_n)$ which is related to the maximum expected peak value deviation $\Delta PV_{\max}$ according to equation (B.3) which is an approximation to numerical results and applies for small $\Delta\varphi_0$ only (< 30°).

$$\Delta\varphi_0(f_n) = \left|\frac{f_{n+1}\cdot\Delta\varphi(f_n) - f_n\cdot\Delta\varphi(f_{n+1})}{f_{n+1}-f_n}\right| \quad \text{(B.2)}$$

$$\Delta PV_{\max} = \pm\max\{0{,}48\ \sin\Delta\varphi_0\}\,\% \text{ within the considered frequency range} \quad \text{(B.3)}$$

For the quantities $\Delta PV_{\max}$ and $\Delta\varphi_0$, tolerances are stated in Table B.1, depending on the frequency ranges (see Clause A.1). These tolerances shall be met by measuring instrumentation corresponding to this Technical Specification in addition to the tolerances specified in ENV 28041.

NOTE 2 It is not reasonable to impose tolerances directly on $\Delta\varphi(f)$ because extremely narrow tolerances would be necessary in order to achieve a certain waveform fidelity. The conversion into $\Delta\varphi_0(f)$ gives the real phase response much more freedom for the same accuracy. This method is essentially identical with the “tangent criterion” used in Annex A, but it is better suited for computer evaluation of test results.

NOTE 3 Depending on the signal waveform the actual peak value deviation will normally be smaller than the maximum peak value deviation which is calculated for the worst-case combination (most unfavourable amplitudes and zero phase angles) of two frequency components. However, in the very unlikely case that more components contribute unfavourably, the actual peak value deviation can even grow higher. Statistically, the term “maximum” may be understood as a very low percentile.

Calibration of the phase frequency response can be performed according to ISO 16063-11 or ISO 16063-12.

**Table B.1 — Tolerances for the characteristic phase deviation $\Delta\varphi_0$ and the maximum peak value deviation $\Delta PV_{max}$**

| | Characteristic phase deviation $\Delta\varphi_0$ | Maximum peak value deviation $\Delta PV_{max}$ |
|---|---|---|
| Range 1 | 6° | ± 5 % |
| Range 2 | 12° | ± 10 % |
| Range 3 | not prescribed | not prescribed |

# Annex C
(informative)

## Alternative parameter to describe single shocks

The acceleration was chosen to describe single shocks because it is the only quantity which can directly be measured in practice. It is not obvious that the acceleration is the most suitable quantity. Therefore, velocity is discussed here as a practical alternative.

The velocity $v_{hF}(t)$ can be computed by integration of the acceleration $a_{hF}(t)$ (see 4.2) as follows:

$$v_{hF}(t) = \int_0^t a_{hF}(\xi)\, \mathrm{d}\xi + v_{hF0} \tag{C.1}$$

where $v_{hF0}$ is the velocity at time $t = 0$.

All parameters described in this Technical Specification with respect to the acceleration can also be applied to the velocity signal.

# Annex D
(normative)

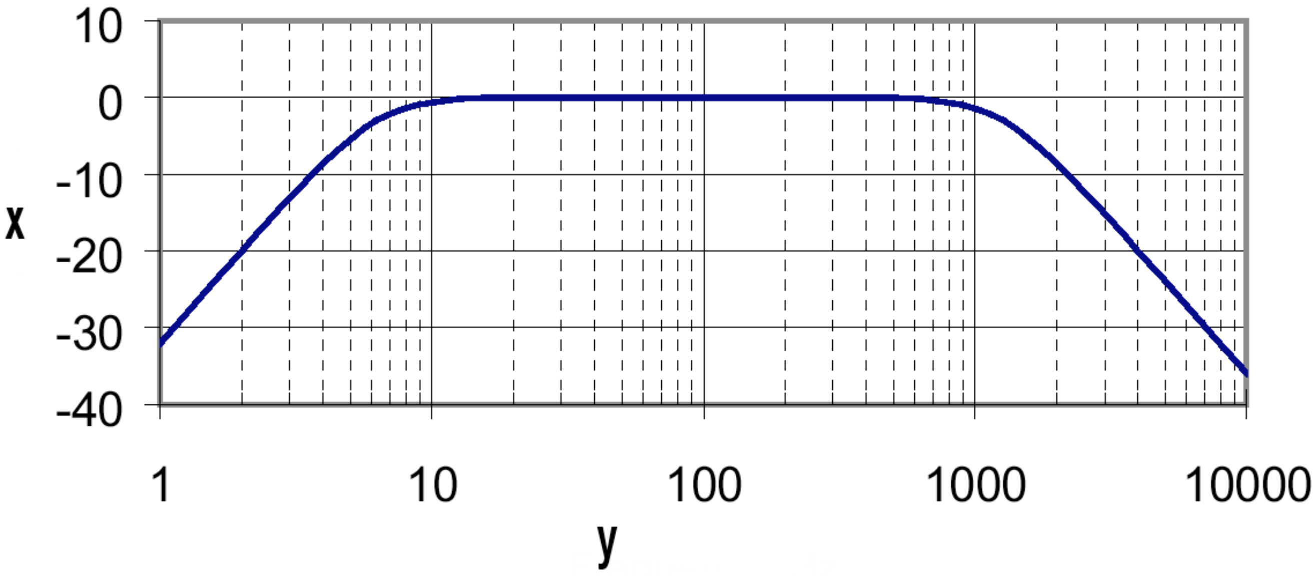
# Filter for flat$_h$ frequency weighting

**Table D.1 — Amplitude frequency response and phase frequency response for the flat$_h$ weighting**

| x | Frequency true<br>Hz | Frequency nominal<br>Hz | Magnitude weighting including band-limiting | Magnitude weighting including band-limiting<br>dB | Tolerance magnitude<br>% | Tolerance magnitude<br>dB | Phase weighting[a] including band-limiting<br>degrees | Tolerance characteristic phase deviation<br>degrees |
|---|---|---|---|---|---|---|---|---|
| -1 | 0,7943 | 0,8 | 0,015845 | -36,00 | +26 / – | +2 / – | -10,30 | – |
| 0 | 1,000 | 1 | 0,025108 | -32,00 | +26 / – | +2 / – | -13,01 | – |
| 1 | 1,259 | 1,25 | 0,039774 | -28,01 | +26 / – | +2 / – | -16,46 | – |
| 2 | 1,585 | 1,6 | 0,062962 | -24,02 | +26 / – | +2 / – | -20,87 | – |
| 3 | 1,995 | 2 | 0,099490 | -20,04 | +26 / – | +2 / – | -26,55 | – |
| 4 | 2,512 | 2,5 | 0,156515 | -16,11 | +26 / – | +2 / – | -33,94 | – |
| 5 | 3,162 | 3,15 | 0,243590 | -12,27 | +26 / – | +2 / – | -43,63 | – |
| 6 | 3,981 | 4 | 0,369831 | -8,64 | +26 / -21 | +2 / -2 | -56,25 | +12 / -12 |
| 7 | 5,012 | 5 | 0,533566 | -5,46 | +26 / -21 | +2 / -2 | -72,13 | +12 / -12 |
| 8 | 6,310 | 6,3 | 0,707059 | -3,01 | +26 / -21 | +2 / -2 | -90,40 | +12 / -12 |
| 9 | 7,943 | 8 | 0,845694 | -1,46 | +26 / -21 | +2 / -2 | -108,69 | +12 / -12 |
| 10 | 10,00 | 10 | 0,929065 | -0,64 | +12 / -11 | +1 / -1 | -124,64 | +12 / -12 |
| 11 | 12,59 | 12,5 | 0,969863 | -0,27 | +12 / -11 | +1 / -1 | -137,38 | +6 / -6 |
| 12 | 15,85 | 16 | 0,987669 | -0,11 | +12 / -11 | +1 / -1 | -147,23 | +6 / -6 |
| 13 | 19,95 | 20 | 0,995036 | -0,04 | +12 / -11 | +1 / -1 | -154,86 | +6 / -6 |
| 14 | 25,12 | 25 | 0,998015 | -0,02 | +12 / -11 | +1 / -1 | -160,85 | +6 / -6 |
| 15 | 31,62 | 31,5 | 0,999208 | -0,01 | +12 / -11 | +1 / -1 | -165,66 | +6 / -6 |
| 16 | 39,81 | 40 | 0,999684 | 0,00 | +12 / -11 | +1 / -1 | -169,61 | +6 / -6 |
| 17 | 50,12 | 50 | 0,999873 | 0,00 | +12 / -11 | +1 / -1 | -172,97 | +6 / -6 |
| 18 | 63,10 | 63 | 0,999947 | 0,00 | +12 / -11 | +1 / -1 | -175,93 | +6 / -6 |
| 19 | 79,43 | 80 | 0,999972 | 0,00 | 0 | 0 | -178,67 | +6 / -6 |
| 20 | 100,0 | 100 | 0,999972 | 0,00 | +12 / -11 | +1 / -1 | -181,33 | +6 / -6 |
| 21 | 125,9 | 125 | 0,999947 | 0,00 | +12 / -11 | +1 / -1 | -184,06 | +6 / -6 |
| 22 | 158,5 | 160 | 0,999873 | 0,00 | +12 / -11 | +1 / -1 | -187,03 | +6 / -6 |
| 23 | 199,5 | 200 | 0,999684 | 0,00 | +12 / -11 | +1 / -1 | -190,38 | +6 / -6 |
| 24 | 251,2 | 250 | 0,999208 | -0,01 | +12 / -11 | +1 / -1 | -194,34 | +6 / -6 |
| 25 | 316,2 | 315 | 0,998015 | -0,02 | +12 / -11 | +1 / -1 | -199,15 | +6 / -6 |
| 26 | 398,1 | 400 | 0,995037 | -0,04 | +12 / -11 | +1 / -1 | -205,14 | +6 / -6 |
| 27 | 501,2 | 500 | 0,987672 | -0,11 | +12 / -11 | +1 / -1 | -212,76 | +6 / -6 |
| 28 | 631,0 | 630 | 0,969871 | -0,27 | +12 / -11 | +1 / -1 | -222,62 | +6 / -6 |
| 29 | 794,3 | 800 | 0,929083 | -0,64 | +12 / -11 | +1 / -1 | -235,36 | +12 / -12 |
| 30 | 1000 | 1000 | 0,845728 | -1,46 | +26 / -21 | +2 / -2 | -251,30 | +12 / -12 |
| 31 | 1259 | 1250 | 0,707109 | -3,01 | +26 / -21 | +2 / -2 | -269,59 | +12 / -12 |
| 32 | 1585 | 1600 | 0,533620 | -5,46 | +26 / -21 | +2 / -2 | -287,86 | +12 / -12 |
| 33 | 1995 | 2000 | 0,369876 | -8,64 | +26 / -21 | +2 / -2 | -303,74 | +12 / -12 |
| 34 | 2512 | 2500 | 0,243622 | -12,27 | +26 / – | +2 / – | -316,37 | – |
| 35 | 3162 | 3150 | 0,156537 | -16,11 | +26 / – | +2 / – | -326,05 | – |
| 36 | 3981 | 4000 | 0,099504 | -20,04 | +26 / – | +2 / – | -333,45 | – |
| 37 | 5012 | 5000 | 0,062971 | -24,02 | +26 / – | +2 / – | -339,13 | – |
| 38 | 6310 | 6300 | 0,039779 | -28,01 | +26 / – | +2 / – | -343,54 | – |
| 39 | 7943 | 8000 | 0,025111 | -32,00 | +26 / – | +2 / – | -346,99 | – |
| 40 | 10000 | 10000 | 0,015847 | -36,00 | +26 / – | +2 / – | -349,69 | – |

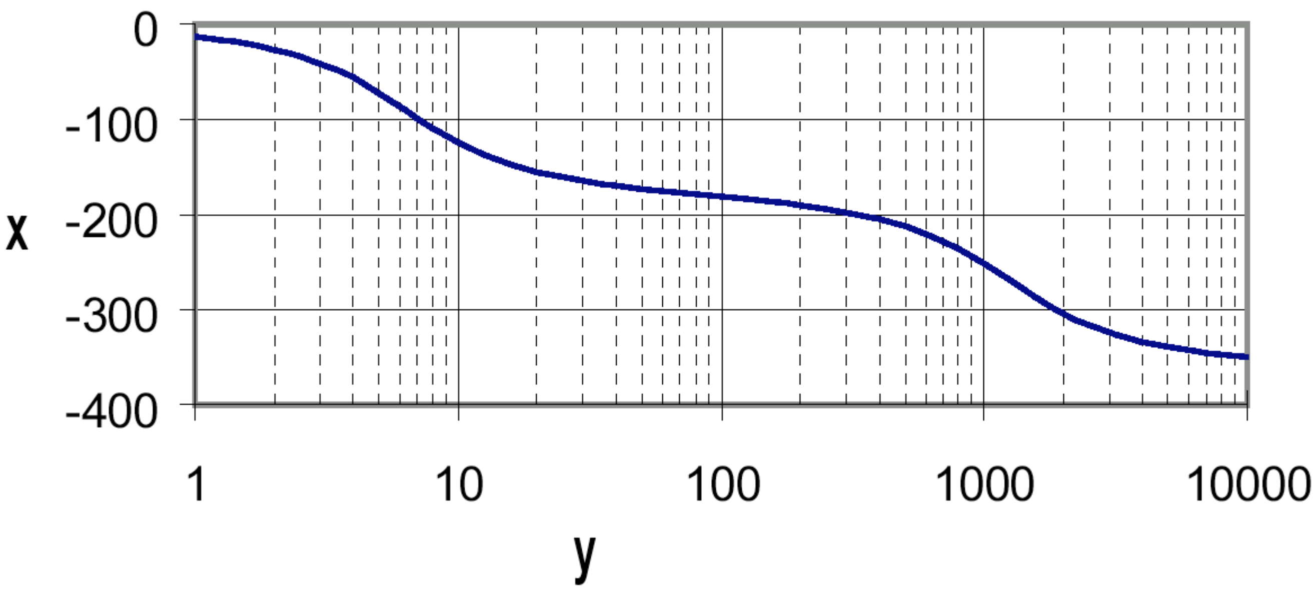
a The phase weighting given has a shift of 180°.

NOTE x is the frequency band number according to EN 61260.




**Key**
x amplitude, dB
y frequency, Hz

**Figure D.1 — Amplitude frequency response for the** flat$_h$ **weighting**




**Key**
x phase, degrees
y frequency, Hz
NOTE The phase frequency response shown has a shift of 180°.

**Figure D.2 — Phase frequency response for the** flat$_h$ **weighting**

# Annex E
(normative)

## Filter for frequency weighting $W_h$ from EN ISO 5349-1

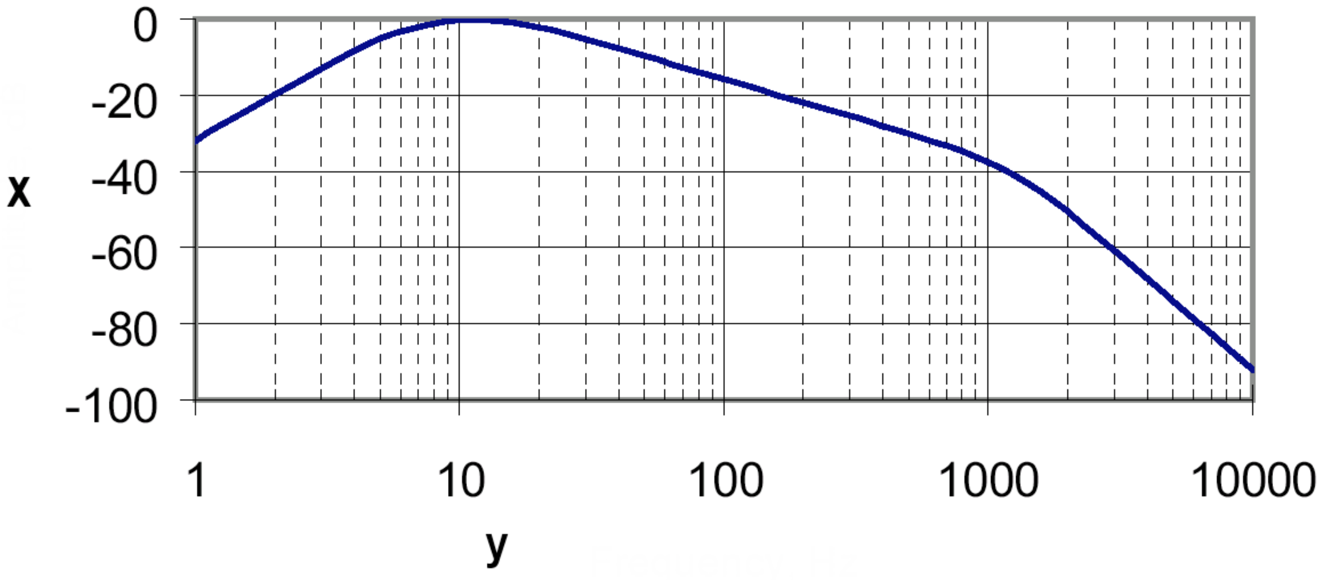
NOTE The frequency weighting $W_h$ is fully defined in EN ISO 5349-1. However, Table E.1 gives a more precise tabulation of this frequency weighting, which is required for the measurement and evaluation of single shocks.

**Table E.1 — Amplitude frequency response and phase frequency response for the weighting $W_h$**

| x | Frequency true Hz | Frequency nominal Hz | Magnitude weighting including band-limiting | Magnitude weighting including band-limiting dB | Tolerance magnitude % | Tolerance magnitude dB | Phase weighting[a] including band-limiting degrees | Tolerance characteristic phase deviation degrees |
|---|---|---|---|---|---|---|---|---|
| -1 | 0,7943 | 0,8 | 0,015856 | -36,00 | +26 / – | +2 / – | -11,92 | – |
| 0 | 1,000 | 1 | 0,025135 | -31,99 | +26 / – | +2 / – | -15,05 | – |
| 1 | 1,259 | 1,25 | 0,039842 | -27,99 | +26 / – | +2 / – | -19,02 | – |
| 2 | 1,585 | 1,6 | 0,063132 | -23,99 | +26 / – | +2 / – | -24,11 | – |
| 3 | 1,995 | 2 | 0,099911 | -20,01 | +26 / – | +2 / – | -30,66 | – |
| 4 | 2,512 | 2,5 | 0,157540 | -16,05 | +26 / – | +2 / – | -39,17 | – |
| 5 | 3,162 | 3,15 | 0,246027 | -12,18 | +26 / – | +2 / – | -50,30 | – |
| 6 | 3,981 | 4 | 0,375354 | -8,51 | +26 / -21 | +2 / -2 | -64,84 | +12 / -12 |
| 7 | 5,012 | 5 | 0,544980 | -5,27 | +26 / -21 | +2 / -2 | -83,30 | +12 / -12 |
| 8 | 6,310 | 6,3 | 0,727160 | -2,77 | +26 / -21 | +2 / -2 | -105,09 | +12 / -12 |
| 9 | 7,943 | 8 | 0,873066 | -1,18 | +26 / -21 | +2 / -2 | -128,25 | +12 / -12 |
| 10 | 10,00 | 10 | 0,951379 | -0,43 | +12 / -11 | +1 / -1 | -150,85 | +12 / -12 |
| 11 | 12,59 | 12,5 | 0,957570 | -0,38 | +12 / -11 | +1 / -1 | -172,19 | +6 / -6 |
| 12 | 15,85 | 16 | 0,895788 | -0,96 | +12 / -11 | +1 / -1 | -192,05 | +6 / -6 |
| 13 | 19,95 | 20 | 0,781965 | -2,14 | +12 / -11 | +1 / -1 | -209,71 | +6 / -6 |
| 14 | 25,12 | 25 | 0,647062 | -3,78 | +12 / -11 | +1 / -1 | -224,37 | +6 / -6 |
| 15 | 31,62 | 31,5 | 0,519149 | -5,69 | +12 / -11 | +1 / -1 | -235,89 | +6 / -6 |
| 16 | 39,81 | 40 | 0,411095 | -7,72 | +12 / -11 | +1 / -1 | -244,78 | +6 / -6 |
| 17 | 50,12 | 50 | 0,324379 | -9,78 | +12 / -11 | +1 / -1 | -251,70 | +6 / -6 |
| 18 | 63,10 | 63 | 0,256041 | -11,83 | +12 / -11 | +1 / -1 | -257,26 | +6 / -6 |
| 19 | 79,43 | 80 | 0,202387 | -13,88 | 0 | 0 | -261,93 | +6 / -6 |
| 20 | 100,0 | 100 | 0,160204 | -15,91 | +12 / -11 | +1 / -1 | -266,06 | +6 / -6 |
| 21 | 125,9 | 125 | 0,126954 | -17,93 | +12 / -11 | +1 / -1 | -269,92 | +6 / -6 |
| 22 | 158,5 | 160 | 0,100680 | -19,94 | +12 / -11 | +1 / -1 | -273,75 | +6 / -6 |
| 23 | 199,5 | 200 | 0,079878 | -21,95 | +12 / -11 | +1 / -1 | -277,80 | +6 / -6 |
| 24 | 251,2 | 250 | 0,063379 | -23,96 | +12 / -11 | +1 / -1 | -282,29 | +6 / -6 |
| 25 | 316,2 | 315 | 0,050263 | -25,98 | +12 / -11 | +1 / -1 | -287,52 | +6 / -6 |
| 26 | 398,1 | 400 | 0,039796 | -28,00 | +12 / -11 | +1 / -1 | -293,85 | +6 / -6 |
| 27 | 501,2 | 500 | 0,031372 | -30,07 | +12 / -11 | +1 / -1 | -301,74 | +6 / -6 |
| 28 | 631,0 | 630 | 0,024468 | -32,23 | +12 / -11 | +1 / -1 | -311,80 | +6 / -6 |
| 29 | 794,3 | 800 | 0,018617 | -34,60 | +12 / -11 | +1 / -1 | -324,71 | +12 / -12 |
| 30 | 1000 | 1000 | 0,013461 | -37,42 | +26 / -21 | +2 / -2 | -340,79 | +12 / -12 |
| 31 | 1259 | 1250 | 0,008939 | -40,97 | +26 / -21 | +2 / -2 | -359,19 | +12 / -12 |
| 32 | 1585 | 1600 | 0,005359 | -45,42 | +26 / -21 | +2 / -2 | -377,54 | +12 / -12 |
| 33 | 1995 | 2000 | 0,002950 | -50,60 | +26 / -21 | +2 / -2 | -393,49 | +12 / -12 |
| 34 | 2512 | 2500 | 0,001544 | -56,23 | +26 / – | +2 / – | -406,17 | – |
| 35 | 3162 | 3150 | 0,000788 | -62,07 | +26 / – | +2 / – | -415,89 | – |
| 36 | 3981 | 4000 | 0,000398 | -68,01 | +26 / – | +2 / – | -423,32 | – |
| 37 | 5012 | 5000 | 0,000200 | -73,98 | +26 / – | +2 / – | -429,03 | – |
| 38 | 6310 | 6300 | 0,000100 | -79,97 | +26 / – | +2 / – | -433,46 | – |
| 39 | 7943 | 8000 | 0,000050 | -85,97 | +26 / – | +2 / – | -436,92 | – |
| 40 | 10000 | 10000 | 0,000025 | -91,96 | +26 / – | +2 / – | -439,64 | – |

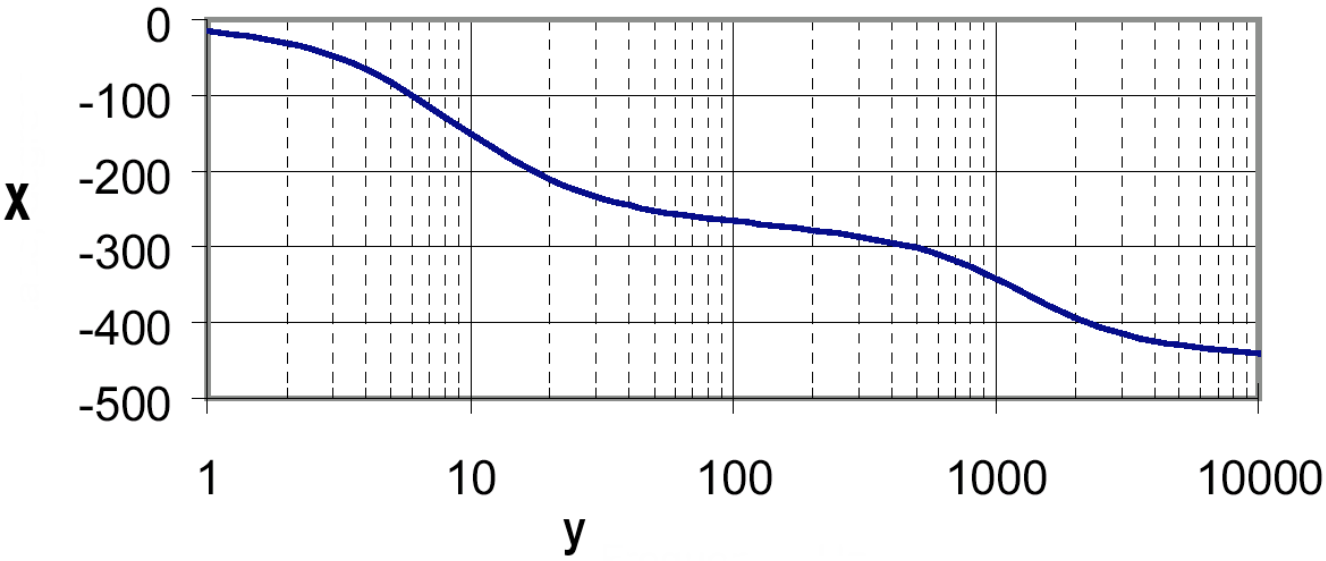
a The phase weighting given has a shift of 180°.

NOTE x is the frequency band number according to EN 61260.




**Key**
x amplitude, dB
y frequency, Hz

**Figure E.1 — Amplitude frequency response for the weighting** $W_h$




NOTE The phase frequency response shown has a shift of 180°.

**Key**
x phase, degrees
y frequency, Hz

**Figure E. 2 — Phase frequency response for the weighting** $W_h$

# Bibliography

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

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

[3] ISO 16063-11, *Methods for the calibration of vibration and shock transducers — Part 11: Primary vibration calibration by laser interferometry*

[4] ISO 16063-12, *Methods for the calibration of vibration and shock transducers — Part 12: Primary vibration calibration by the reciprocity method*

[5] H. Dupuis, N. Schäfer: Effects of impulse vibration on the hand-arm system. Scand. J. Work Eviron. Health, 1986, pp. 320-322

[6] H. Lindell, I. Lönnroth, H. Ottertun: Transient vibrations from impact wrenches cause damages on blood cell and the effects are not taken into account by ISO 5349. Proceedings of the 8th International Conference on Hand-Arm Vibration, Umeå, Sweden, 1998

[7] N. Schäfer, H. Dupuis, E. Hartung: Acute effects of shock-type vibration transmitted to the hand-arm system. Int. Arch. Occup. Environ. Health, 55, 1984, pp. 49-59

[8] Th. Schenk: Measurement of single shocks affecting the hand-arm system. Proceedings of the 6th International Conference on Hand-Arm Vibration, Published by Hauptverband der gewerblichen Berufsgenossenschaften, Sankt Augustin, Germany, 1993

[9] J. Starck: High impulse acceleration levels in hand-held vibratory tools. Scand. J. Work Eviron. Health, 10, 1984, pp. 171-178

[10] J. Starck, P. Jussi, P. Ilmari: Physical characteristics of vibration in relation to vibration-induced white finger. Am. Ind. Hyg. Assoc., 51-4, 1990, pp. 179-184

[11] Stockholm Workshop 94: Hand-arm vibration syndrome – Diagnostic and quantitative relationships to exposure. Arbete och Hälsa, 5, 1995

[12] EN 61260, *Electroacoustics — Octave-band and fractional-octave-band filters (IEC 61260:1995)*

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