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Mechanical vibration — Measurement and evaluation of human exposure to hand transmitted vibration — Supplementary method for assessing risk of vascular disorders

Vibrations mécaniques — Mesurage et évaluation de l'exposition des individus aux vibrations transmises par la main — Méthode supplémentaire pour l'évaluation du risque de blessure vasculaire

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

Introduction

This document is a result of analyses of application of the W_h frequency weighting defined by ISO 5349-1 to the risk of vascular hand-arm vibration disorders. For vibration exposures dominated by particularly high or particularly low frequencies of vibration, there is evidence that weightings based on the (20 to 400) Hz frequency range may give an improved prediction of risk of vascular disorders over the weighting W_h.

This document proposes a frequency weighting and risk assessment parameter that can be used to supplement the method defined in ISO 5349-1. The purpose of this document is to

a) define a supplementary evaluation methodology that can be used in addition to that given in ISO 5349-1, and

b) ensure that additional data are collected in a common format to help to improve knowledge and understanding of vascular vibration risks.

Mechanical vibration — Measurement and evaluation of human exposure to hand transmitted vibration — Supplementary method for assessing risk of vascular disorders

1 Scope

This document provides guidance on a supplementary method to that defined in ISO 5349-1 for measuring and reporting hand-transmitted vibration exposures. The method defined in this document provides an improved assessment methodology for evaluating vascular hand-arm vibration risks (vibration white finger). This document does not apply for other health effects (e.g. sensorineural and musculoskeletal disorders) induced from hand-transmitted vibration exposure (see ISO 5349-1:2001, Annex B).

This document is intended to facilitate future research on hand-arm vibration risks. It can be used to supplement the data given by the ISO 5349-1 methodology.

This document cannot be used as an alternative to ISO 5349-1. Data derived from this document cannot be used in place of ISO 5349-1 data for fulfilling duties under national regulations, guidance or recommendations for either workplace vibration exposures or machinery vibration emissions.

The methodology defined in this document is based on biomechanical and epidemiological studies which are reviewed in Annex A. Also provided in Annex A is tentative information on a relationship between vibration exposure and risk of developing vascular hand-arm vibration disorders.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in ISO 2041 and ISO 5349-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

Symbol	Definition
$a_{pi}(t)$	instantaneous value of the hand-transmitted vibration for the axis *i* at time *t*, in metres per second squared (m/s²) frequency-weighted according to the hand-arm vascular weighting W_p;
a_{pi}	root-mean-square (r.m.s.) value of the hand-transmitted vibration for the axis *i* in metres per second squared (m/s²) frequency-weighted according to the hand-arm vascular weighting W_p;
$a_{pv}(t)$	instantaneous value of the hand-transmitted vibration total value at time *t*, in metres per second squared (m/s²) frequency-weighted according to the hand-arm vascular weighting W_p: $a_{pv}(t)=\sqrt{a_{px}^2(t)+a_{py}^2(t)+a_{pz}^2(t)}$;
a_{pv}	r.m.s. vibration total value of the hand-transmitted vibration, in metres per second squared (m/s²) frequency-weighted according to the hand-arm vascular weighting W_p;

Symbol	Definition
$A_p(8)$	daily vibration exposure normalized to an 8-hour day, frequency-weighted according to the hand-arm vascular weighting W_p;
E_p	vibration exposure value, frequency-weighted according to the hand-arm vascular weighting W_p;
$E_{p,d}$	vibration exposure value determined over a working day;
$E_{p,l}$	vibration exposure value determined over a working lifetime;
W_p	frequency weighting characteristic for the vascular component of the hand-transmitted vibration syndrome.

4 Characterization of hand-transmitted vibration

4.1 General considerations

The method specified in this document takes account of the following factors which are believed to influence the vascular effects of human exposure to hand-transmitted vibration in working conditions:

a) the frequency spectrum of vibration;

b) the magnitude of vibration;

c) the duration of exposure per working day.

Other factors which may influence the effects of vibration exposure, but for which standardized methods for reporting do not yet exist, are listed in ISO 5349-1:2001, Annex D.

4.2 Measuring equipment for hand-transmitted vibration

4.2.1 General

Measurement of hand-transmitted vibration should be undertaken using instrumentation conforming as far as is possible to the requirements of ISO 8041-1. This equipment should be checked for correct operation before and after use. The calibration should be traceable to a recognized standard maintained by an accredited laboratory.

ISO 8041-1:2017 does not provide specifications for the W_p frequency weighting. Where possible, measurement equipment should conform to the basic requirements of ISO 8041-1.

4.2.2 Vibration transducers

The vibration transducer requirements should be the same as those specified in ISO 5349-1:2001, 4.2.2.

4.2.3 Location and orientation of transducers

The location and orientation of vibration transducers should be the same as those specified in ISO 5349-1:2001, 4.2.3.

4.2.4 Mounting of transducers

The mounting requirements for vibration transducers should be the same as those specified in ISO 5349-1:2001, 4.2.4.

NOTE The consequence of poor mounting may be more noticeable with W_p than with W_h.

4.2.5 Coupling of the hand to the vibration source

The coupling of the hand requirements should be the same as those specified in ISO 5349-1:2001, 4.3.

4.3 Quantity to be measured

The primary quantity used to describe the magnitude of the vibration shall be the root-mean-square (r.m.s.) frequency-weighted acceleration expressed in metres per second squared (m/s^2).

The measurement of frequency-weighted acceleration requires the application of a frequency weighting and band-limiting filters. The frequency weighting W_p reflects the assumed importance of different frequencies in causing vascular disorders of the hand. The characteristics of the W_p frequency weighting and methods for band-limiting are given in Annex B.

The r.m.s. value is measured using a linear integration method. The integration time should be chosen such that a representative sample of the vibration signal is used (see ISO 5349-2).

4.4 Multi-axis vibration

It is known that on most power tools the vibration entering the hand contains contributions from all three measurement directions. It is assumed that vibration in each of the three directions is equally detrimental. Measurements should therefore be made for all three directions. The frequency-weighted r.m.s. acceleration values for the x-, y- and z-axes, a_{px}, a_{py} and a_{pz}, should be reported separately.

The evaluation of vibration exposure (see Clause 5), however, is based on a quantity that combines all three axes. This is the vibration total value, a_{pv}, and is defined as the root-sum-of-squares of the three component values, as shown by Formula (1):

$$a_{pv} = \sqrt{a_{px}^2 + a_{py}^2 + a_{pz}^2} \quad (1)$$

Annex C provides some example values for a_{pv} and compares these with equivalent values a_{hv} using the ISO 5349-1 frequency weighting.

5 Characterization of hand-transmitted vibration exposure for vascular disorders

5.1 General

Vibration exposure is dependent on the magnitude of the vibration and on the duration of the exposure. In order to apply the guidance on the vascular health effects given in Annex A, the vibration magnitude is represented by a frequency-weighted vibration total value a_{pv}.

5.2 Daily exposure duration

The requirements for assessing daily vibration exposure times should be the same as those specified in ISO 5349-1:2001, 5.2.

5.3 Vibration exposure

A value for an individual's vibration exposure in a working day is derived from the magnitude of the vibration (vibration total values) and the daily exposure durations.

The daily vibration exposure should be expressed in terms of the frequency-weighted exposure vibration value, E_p, as shown by Formula (2):

$$E_p = \sqrt{\int_{t_1}^{t_2} a_{pv}^2(t)\,dt} \quad \left(\mathrm{m/s^{1,5}}\right) \quad (2)$$

where

t_1 is the time at the start of vibration exposure, expressed in seconds (s);

t_2 is the time at the end of vibration exposure, expressed in seconds (s).

If the work is such that the vibration exposure consists of several operations with different vibration magnitudes, then the vibration exposure, E_p, should be obtained using Formula (3):

$$E_p = \sqrt{\sum_{i=1}^{n} a_{pvi}^2 T_i} \quad (\mathrm{m/s^{1,5}}) \tag{3}$$

where

a_{pvi} is the vibration total value for the i^{th} operation;

n is the number of individual vibration exposures;

T_i is the duration of the i^{th} operation, expressed in seconds (s).

When the E_p value is determined over a single working day it should be denoted as, $E_{p,d}$. The E_p value may also be estimated for a lifetime exposure, where it is denoted as $E_{p,l}$, as shown by Formula (4):

$$E_{p,l} = \sqrt{\sum_{j=1}^{m} E_{p,d,j}} \quad (\mathrm{m/s^{1,5}}) \tag{4}$$

where

$E_{p,d,j}$ is the daily vibration exposure for the j^{th} day;

m is the number of days with vibration exposure in a lifetime.

To prevent confusion with the W_h weighted $A(8)$ as defined by ISO 5349-1, it is recommended that W_p weighted exposures are expressed as exposure values $E_{p,d}$. However, if necessary, the W_p weighted daily vibration exposure $A_p(8)$ may be obtained using Formula (5):

$$A_p(8) = \sqrt{\sum_{i=1}^{n} a_{pvi}^2 \frac{T_i}{T_0}} \quad (\mathrm{m/s^2}) \tag{5}$$

where T_0 is the reference time of 8 h (28 800 s).

Therefore:

$$A_p(8) = \frac{E_{p,d}}{\sqrt{T_0}}$$

6 Information to be reported

In addition to the information to be reported in accordance with ISO 5349-1:2001, Clause 6, the following information should be reported:

a) the individual root-mean-square, single-axis frequency-weighted accelerations measured with the W_p weighting;

b) the vibration total value, a_{pv}, for each operation;

c) the calculated vibration exposure, $E_{p,d}$, for a working day.

Additionally, the lifetime vibration exposure, $E_{p,l}$, may also be reported.

Annex A
(informative)

Biomechanical and epidemiological basis for weighting W_p

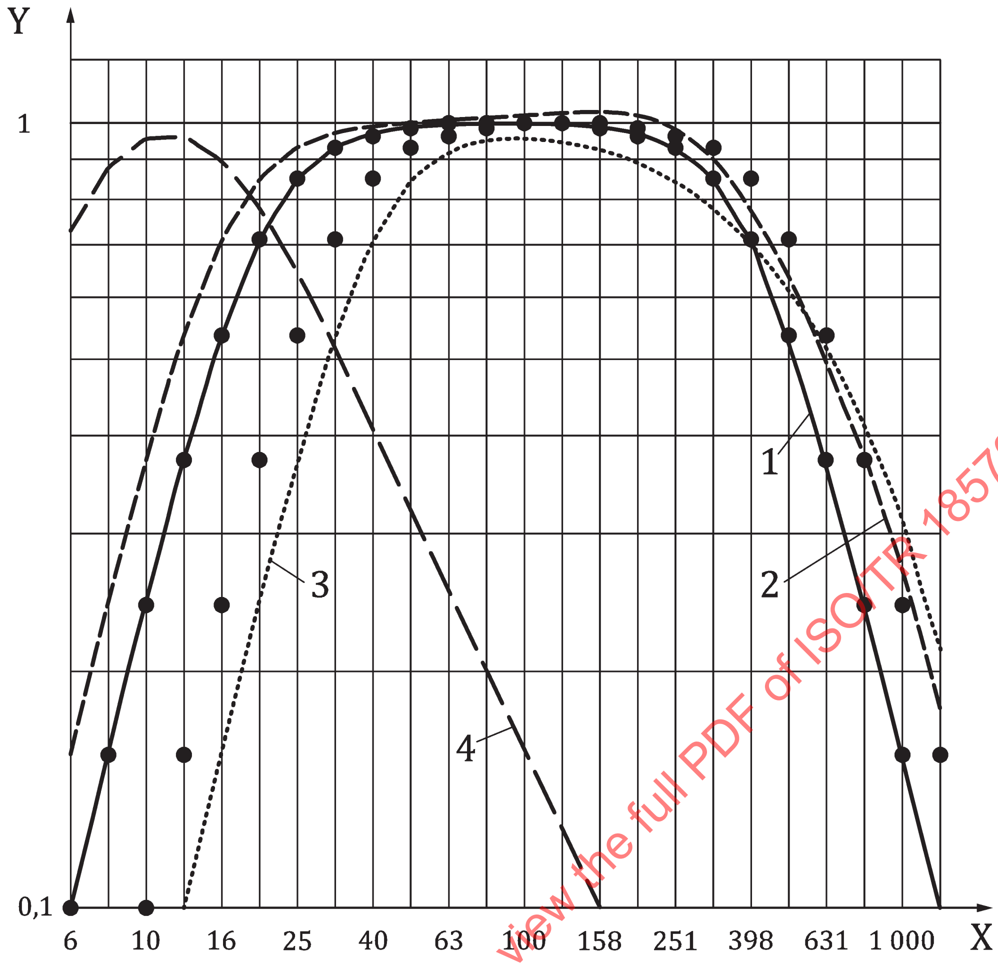
A frequency weighting is required to quantify the risk of developing symptoms of vibration white finger (VWF) from exposing the hands to vibration. The frequency weighting accounts for the relative hazard posed by vibration at different frequencies. Predictions of risk using the procedures described in annexes to ISO 5349:1986 and ISO 5349-1:2001 have been found to agree with the observed latencies of finger blanching (i.e. the years of exposure to vibration prior to the appearance of the first white finger) for some occupationally-exposed population groups, as well as to underestimate or overestimate the risk for some situations.[1],[2] The risk of developing VWF is overestimated for power tools such as rock drills, pavement breakers and sand rammers, and underestimated for riveting tools.[1–7] The discrepancies between predictions of the risk of developing VWF and the experience of population groups occupationally exposed to vibration have been attributed, in part, to the frequency weighting recommended in ISO 5349-1.

Frequency weightings can be derived, in principle, from physiological or patho-physiological responses to vibration in humans or animals, from biodynamic models characterizing vibration entering the hand-arm system, or from epidemiological studies of population groups in which vibration exposures have been measured or can be estimated. Attempts to construct frequencies weightings from physiological responses of humans or animals, while informative, have not so far proved to be definitive. Most information on the form of frequency weighting necessary to characterize the development of VWF has come from biodynamic models contained in ISO 10068:2012, and from analyses of epidemiological studies using trial frequency weightings.[8–12]

The results of the three most definitive studies are summarized in Figure A.1, see Reference [12]. The frequency weightings derived by Tominaga (W_{hT}) and Dong et al. (W_{hf}) are presented in the form used in analyses by Pitts et al. and Bovenzi, see Reference [13], alongside the W_h weightings. The weighting derived by Brammer and Pitts defines a range of frequencies that lies between the black dots. Each frequency weighting applies to vibration expressed as either the dominant single axis r.m.s. acceleration or vibration total value (i.e. vector sum acceleration). W_p is compatible with the results of all these studies and provides the best estimate of the frequency weighting required to quantify the risk of developing symptoms of VWF from exposing the hands to vibration.

The analysis of Brammer and Pitts[12] also permits an estimate to be made of the least daily vibration exposure, $E_{p,d}$, at which symptoms of VWF may be expected to occur. The daily exposure threshold for the onset and continuing development of VWF is in the range for $E_{p,d}$, of 1150 m/s^{1,5} to 1750 m/s^{1,5}.

Some variation in the threshold can be expected for different exposure conditions. Upper values in the range pertain to exposures for a working day evaluated using vibration total values according to 5.3. Lower values in the range pertain to situations in which it is not possible to obtain vibration total values, and exposures have to be constructed from dominant single-axis accelerations. It should be noted that the threshold range pertains only to the risk of developing vascular hand-arm vibration disorders.



Key

X one-third-octave-band centre frequency (Hz)

Y gain factor

1 W_p

2 W_{hf}

3 W_{hT}

4 W_h

NOTE Curves are identified in the text (reproduced from Reference [12]).

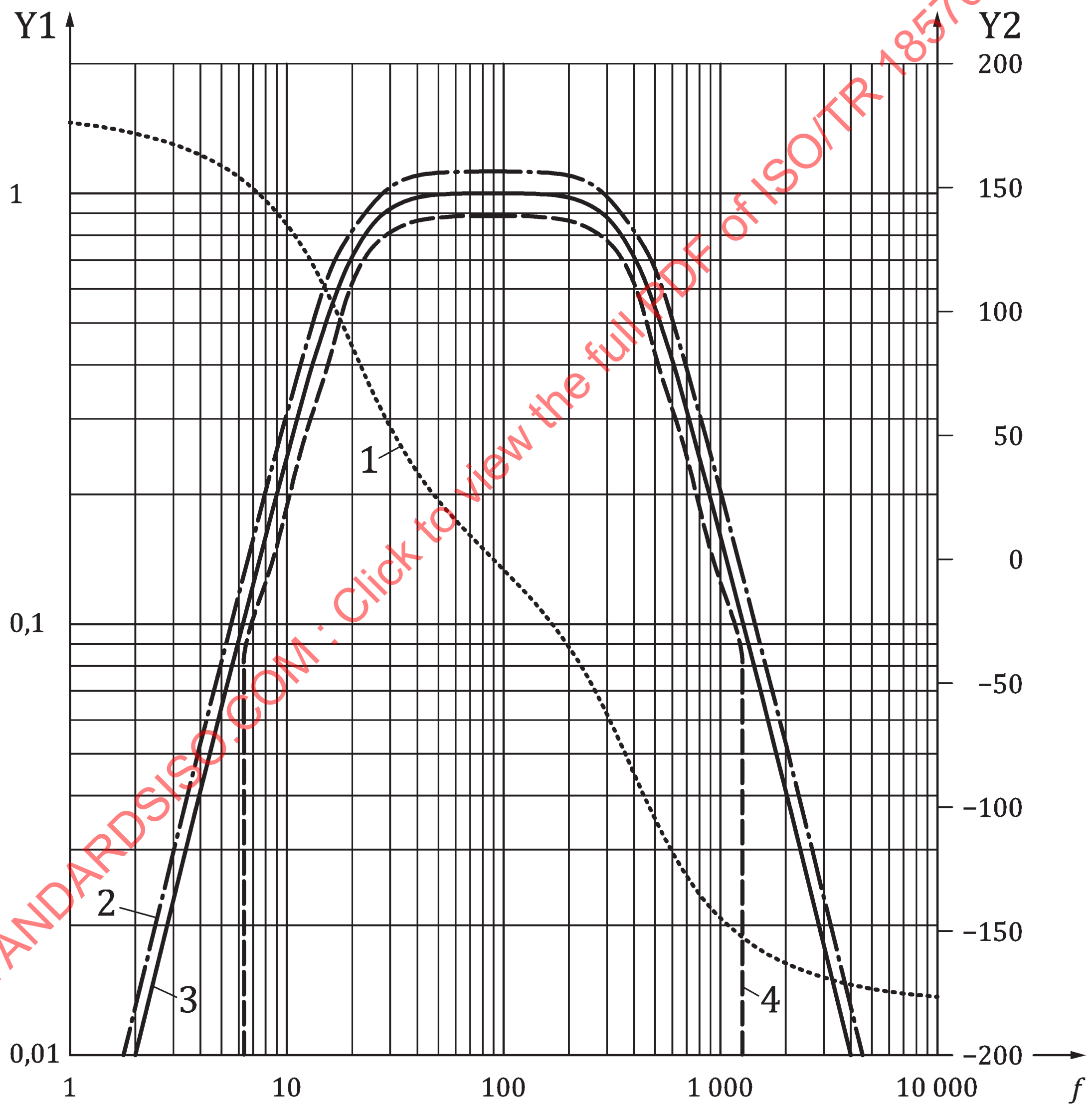
Figure A.1 — Frequency weightings for development of VWF from biodynamic and epidemiological analyses

Annex B
(informative)

Frequency weighting definitions

B.1 General

The frequency weighting W_p can be realized by a simple band-limiting filter, with upper and lower band-pass characteristics as specified in Table B.1.



Key

f frequency (Hz)

Y1 weighting factor

Y2 phase (degrees)

1 W_p phase

2 Tol +

3 W_p

4 Tol -

Figure B.1 — Characteristics of the frequency weighting W_p

Table B.1 — Band-pass characteristics for frequency weighting W_p

Weighting	Band-limiting parameters			
	f_1 (Hz)	Q_1	f_2 (Hz)	Q_2
W_p	$10^{13/10}$ (≈ 20 Hz)	$\frac{1}{\sqrt{2}}$	$10^{26/10}$ (≈ 400 Hz)	$\frac{1}{\sqrt{2}}$

B.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 by high pass and low pass, as shown by Formulae (B.1) and (B.2), respectively:

High pass:

$$H_h(s) = \frac{1}{1 + \frac{\omega_1}{Q_1 s} + \left(\frac{\omega_1}{s}\right)^2} \tag{B.1}$$

Low pass:

$$H_l(s) = \frac{1}{1 + \frac{s}{Q_2 \omega_2} + \left(\frac{s}{\omega_2}\right)^2} \tag{B.2}$$

The product $H_h(s) \times H_l(s)$ represents the band limiting transfer function.

The angular frequencies ω_1 and ω_2 (given by $\omega_i = 2\pi f_i$ where f_i are the frequencies f_1 and f_2 in Table B.1) and the resonant quality factors Q_1 and Q_2 are parameters of the transfer functions in Formulae (B.1) and (B.2) which determine the overall acceleration frequency weightings.

B.3 Overall frequency weighting

The overall frequency weighting function for weighting W_p is in general a product of band limiting, a-v transition and upward-step filters. For W_p only the band limiting transfer functions of B.2 apply, i.e. Formula (B.3):

$$H(s) = H_h(s) \times H_l(s) \tag{B.3}$$

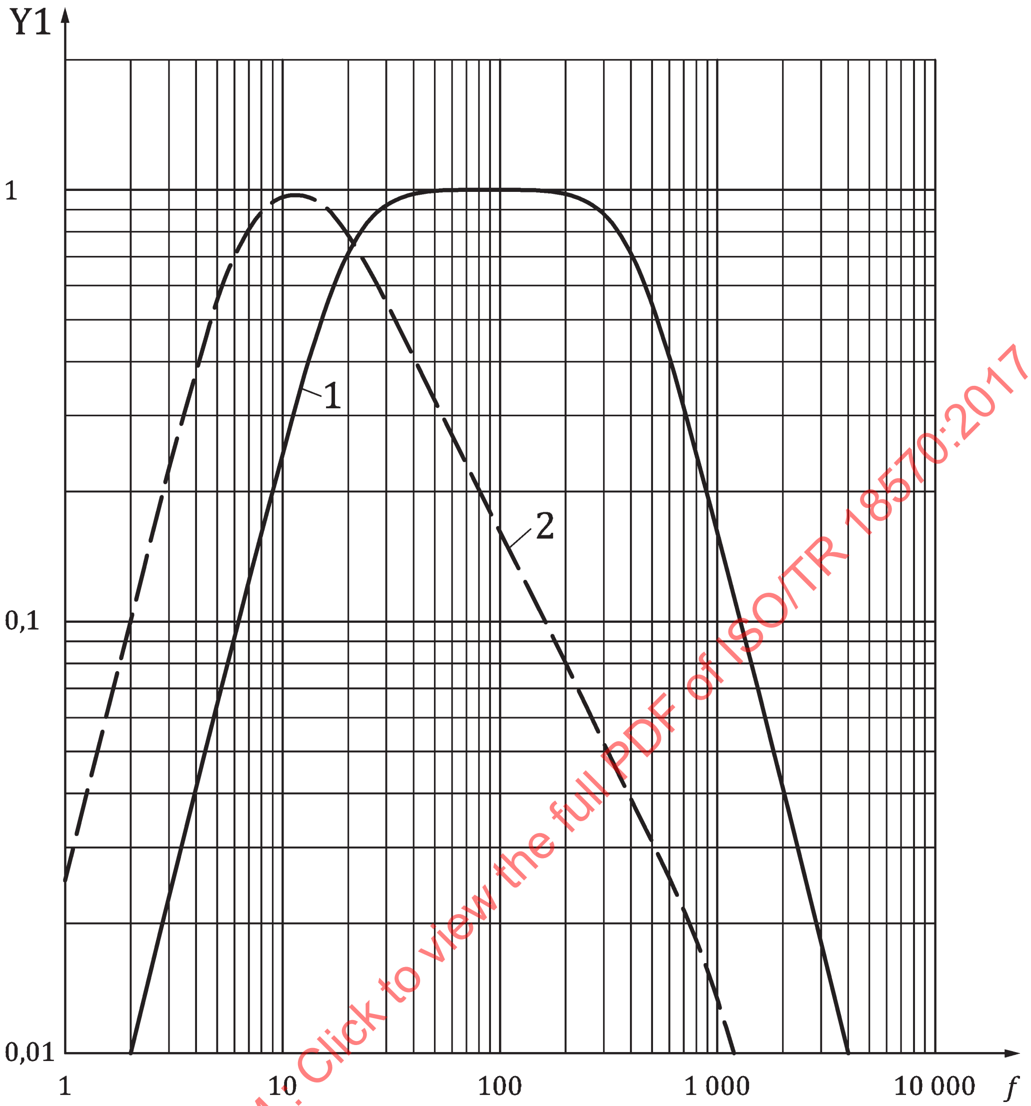
The most common interpretation of this formula is in the frequency domain, where it describes the modulus (magnitude) and phase of the frequency weighting as a function of the imaginary angular frequency: $s = j2\pi f$.

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

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

The weighting curve W_p is shown in Figure B.1 and Table B.2 gives the magnitude and phase of the frequency weighting defined by Formulae (B.1) to (B.3) and Table B.1, as functions of frequency *f*.

Figure B.2 shows a comparison of frequency weightings W_p and W_h.



Key

f	frequency (Hz)	1	W_p
Y1	weighting factor	2	W_h

Figure B.2 — Comparison of frequency weightings W_p and W_h

B.4 Suggested tolerances

In the absence of tolerances defined in ISO 8041-1:2017, it is suggested that the following tolerances are applied:

a) between lower and upper cut-off frequencies: +12 %, −11 %;

b) between lower cut-off frequency and 2 octaves below and between upper cut-off frequency and 2 octaves above: +26 %, −21 %;

c) more than 2 octaves below the lower cut-off frequency and more than 2 octaves above the upper cut-off frequency: +12 %, −100 %.

These tolerances are illustrated in Figure B.1.

It is the role of ISO 8041-1 to provide instrumentation tolerances. Tolerances for the supplementary weighting W_p are not currently provided by ISO 8041-1:2017. While this remains the case the tolerances given here are recommended.

Table B.2 — W_p frequency weighting factors

Band no	Frequency (Hz)	W_p	Suggested tolerance minus (%)	Suggested tolerance plus (%)	W_p (dB)	W_p phase (degrees)
0	1	0,002 512	−100	26	−52,0	175,7
1	1,258 925	0,003 981	−100	26	−48,0	174,6
2	1,584 893	0,006 309	−100	26	−44,0	173,2
3	1,995 262	0,01	−100	26	−40,0	171,5
4	2,511 886	0,015 847	−100	26	−36,0	169,2
5	3,162 278	0,025 111	−100	26	−32,0	166,4
6	3,981 072	0,039 779	−100	26	−28,0	162,8
7	5,011 872	0,062 971	−100	26	−24,0	158,2
8	6,309 573	0,099 504	−21	26	−20,0	152,3
9	7,943 282	0,156 536	−21	26	−16,1	144,6
10	10	0,243 62	−21	26	−12,3	134,5
11	12,589 25	0,369 874	−21	26	−8,6	121,4
12	15,848 93	0,533 616	−21	26	−5,5	105,0
13	19,952 62	0,707 105	−11	12	−3,0	85,9
14	25,118 86	0,845 719	−11	12	−1,5	66,7
15	31,622 78	0,929 063	−11	12	−0,6	49,5
16	39,810 72	0,969 822	−11	12	−0,3	35,3
17	50,118 72	0,987 548	−11	12	−0,1	23,5
18	63,095 73	0,994 723	−11	12	0,0	13,5
19	79,432 82	0,997 225	−11	12	0,0	4,4
20	100	0,997 225	−11	12	0,0	−4,4
21	125,892 5	0,994 723	−11	12	0,0	−13,5
22	158,489 3	0,987 548	−11	12	−0,1	−23,5
23	199,526 2	0,969 822	−11	12	−0,3	−35,3
24	251,188 6	0,929 063	−11	12	−0,6	−49,5
25	316,227 8	0,845 719	−11	12	−1,5	−66,7
26	398,107 2	0,707 105	−11	12	−3,0	−85,9
27	501,187 2	0,533 616	−21	26	−5,5	−105,0
28	630,957 3	0,369 874	−21	26	−8,6	−121,4
29	794,328 2	0,243 62	−21	26	−12,3	−134,5
30	1 000	0,156 536	−21	26	−16,1	−144,6
31	1 258,925	0,099 504	−21	26	−20,0	−152,3
32	1 584,893	0,062 971	−100	26	−24,0	−158,2
33	1 995,262	0,039 779	−100	26	−28,0	−162,8
34	2 511,886	0,025 111	−100	26	−32,0	−166,4
35	3 162,278	0,015 847	−100	26	−36,0	−169,2
36	3 981,072	0,01	−100	26	−40,0	−171,5

Table B.2 *(continued)*

Band no	**Frequency** (Hz)	W_p	**Suggested tolerance minus** (%)	**Suggested tolerance plus** (%)	W_p (dB)	W_p **phase** (degrees)
37	5 011,872	0,006 309	−100	26	−44,0	−173,2
38	6 309,573	0,003 981	−100	26	−48,0	−174,6
39	7 943,282	0,002 512	−100	26	−52,0	−175,7
40	10 000	0,001 585	−100	26	−56,0	−176,6