International Standard 5349

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Mechanical vibration — Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration

Vibrations mécaniques — Principes directeurs pour le mesurage et l'évaluation de l'exposition des individus aux vibrations transmises par la main

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Foreword

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International Standard ISO 5349 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock.*

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Mechanical vibration — Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration

0 Introduction

Intensive vibration can be transmitted to the hands and arms of operators from vibrating tools, vibrating machinery or vibrating workpieces. Such situations occur, for example, when a person handles tools such as pneumatic, electric, hydraulic or engine-driven chain saws, percussive tools or grinders. Depending on the type and place of work, vibration can enter one arm only or both arms simultaneously, and may be transmitted through the hand and arm to the shoulder. The vibration of body parts and the perceived vibration are frequently the source of discomfort and possibly reduced proficiency. Continued, habitual use of many vibrating tools has been found to be connected with various patterns of diseases affecting the blood vessels, nerves, bones, joints, muscles or connective tissues of the hand and forearm.

The vibration exposures required to cause these disorders are not known exactly, either with respect to vibration intensity and frequency spectrum, or with respect to daily and cumulative exposure duration. In view of the complexity of the problem and the shortage of quantitative data concerning the occupational health effect of hand-transmitted vibration, it is difficult to propose a comprehensive method for assessing vibration exposure. However, based on the limited data available and on experience with current exposure conditions, the information proposed in this International Standard together with its annexes represents the best guidance available to protect the majority of workers against serious health impairment and to assist in the development of hand-operated tools the use of which will reduce the risk of disorders in man caused by vibrations.

The purpose of this International Standard is to further the gathering of consistent data in order to improve occupational safety. In particular, it is hoped that the data will serve to extend the present knowledge on the dose-effect relationship.

1 Scope and field of application

This International Standard applies to periodic and to random or non-periodic vibration. Provisionally, this International Standard may also be applied to repeated shock type excitation.

This International Standard specifies general methods for measuring and reporting hand-transmitted vibration exposure in three orthogonal axes for the one-third octave bands, having centre frequencies from 6,3 to 1 250 Hz, the octave bands, having centre frequencies from 8 to 1 000 Hz and a frequency-weighted measure which covers the frequency range from 5,6 to 1 400 Hz.

This International Standard, together with its annexes, provides guidance for the evaluation of hand-transmitted vibration specified in terms of a frequency-weighted vibration acceleration and daily exposure time. It does not define the limits of safe exposure.

The guidance proposed in this International Standard is derived from a consensus of opinion based upon data available from both practical experience and laboratory experimentation concerning human response to hand-transmitted vibration. It cannot be taken to define completely safe exposure ranges in which vibration diseases cannot occur.

This International Standard does not specify the risk factor of health impairment for different operational processes, tools and machines.

To facilitate further progress in this field and to allow the quantitative comparison of exposure data, uniform methods for measuring and reporting exposure of human beings to hand-transmitted vibration are desirable. Additional standards are to be considered for the vibration measurement of specific tools and processes.

2 References

ISO 2631, *Evaluation of human exposure to whole-body vibration.*

ISO 5347, *Methods for the calibration of vibration and shock pick-ups.* 1)

ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers.* 1)

ISO 5805, *Mechanical vibration and shock affecting man — Vocabulary.*

ISO 8041, *Human-response vibration measuring instrumentation.* 1)

1) At present at the stage of draft.

IEC Publication 184, *Methods for specifying the characteristics of electro-mechanical transducers for shock and vibration measurements.*

IEC Publication 222, *Methods for specifying the characteristics of auxiliary equipment for shock and vibration measurement.*

IEC Publication 225, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

3 Characterization of hand-transmitted vibration

3.1 General considerations

The severity of the biological effects of hand-transmitted vibration in working conditions is influenced by

a) the frequency spectrum of vibration;

b) the magnitude of vibration;

c) the duration of exposure per working day;

d) the temporal exposure pattern and working method, that is the length and frequency of work and rest spells; whether the tool is laid aside or held idling during breaks, etc.;

e) the cumulative exposure to date;

f) the magnitude and direction of forces applied by the operator through his hands to the tool or the workpiece;

g) the posture of the hand, arm and body position during exposure (angles of wrist, elbow and shoulder joints);

h) the type and condition of vibrating machinery, hand-tool or workpiece;

i) the area and location of the parts of the hands which are exposed to vibration.

The severity of the biological effects of hand-transmitted vibration in working conditions may be influenced by

a) the direction of the vibration transmitted to the hand;

b) the method of working and the operator's skill;

c) any predisposing factors in the individual's health.

The following factors may specifically affect the circulation changes caused by hand-arm vibration:

a) climatic conditions;

b) diseases which affect the circulation;

c) agents affecting the peripheral circulation, such as smoking, certain medicines or chemicals in the working environment;

d) noise.

Although the importance of all the factors listed with respect to the generation of vibration disorders is not yet known in sufficient detail, reporting of all factors is considered desirable in order to enable the collection of meaningful exposure histories. It is also important to report the measurement procedure and the statistical techniques used to evaluate the vibration data.

3.2 Direction of vibration

The directions of vibration transmitted to the hand should be reported in the appropriate directions of an orthogonal co-ordinate system as suggested in figure 1.

For vibration measurements, the orientation of the coordinate system may be defined with reference to an appropriate basicentric coordinate system [see figure 1a)] originating, for example, in a vibrating appliance, workpiece, handle or control device gripped by the hand.

NOTE — Current methods of vibration assessment are based on the directional component with the largest weighted vibration acceleration.

In order to avoid a conflict between the terminology proposed here and that used generally in biodynamics to define human whole-body vibration exposure (see ISO 2631), it is proposed that the motions of the hand for the various directions of the coordinate system be designated by the parenthetical word "(hand)" or the subscript "h". (The acceleration of the hand in the z direction would be designated $a_{z\,(\mathrm{hand})}$ or $a_{z,\,\mathrm{h}}$, and similarly for directions x and y. Whole-body acceleration in the longitudinal axis is designated by a_z, and similarly for directions x and y.)

3.3 Magnitude of vibration

3.3.1 The primary quantity used to describe the magnitude of the vibration shall be acceleration which should normally be expressed in metres per second squared (m/s^2). The magnitude of the vibration should be expressed as a root-mean-square (r.m.s.) acceleration value. The acceleration may also be measured with a weighting network as defined in 3.4.5 and table 1.

Acceleration measured in conjunction with frequency analysis equipment (for example one-third octave band filters) should not be weighted.

The weighting characteristics of the filter described in table 1 require that the attenuation of the filter be zero up to a frequency of 16 Hz and then increase at 6 dB/octave above that frequency.

The data for these weighting characteristics are derived from laboratory studies of human response to hand-transmitted vibration.

3.3.2 The magnitude of the vibration may also be expressed in terms of an acceleration level, in decibels (dB). This is defined as

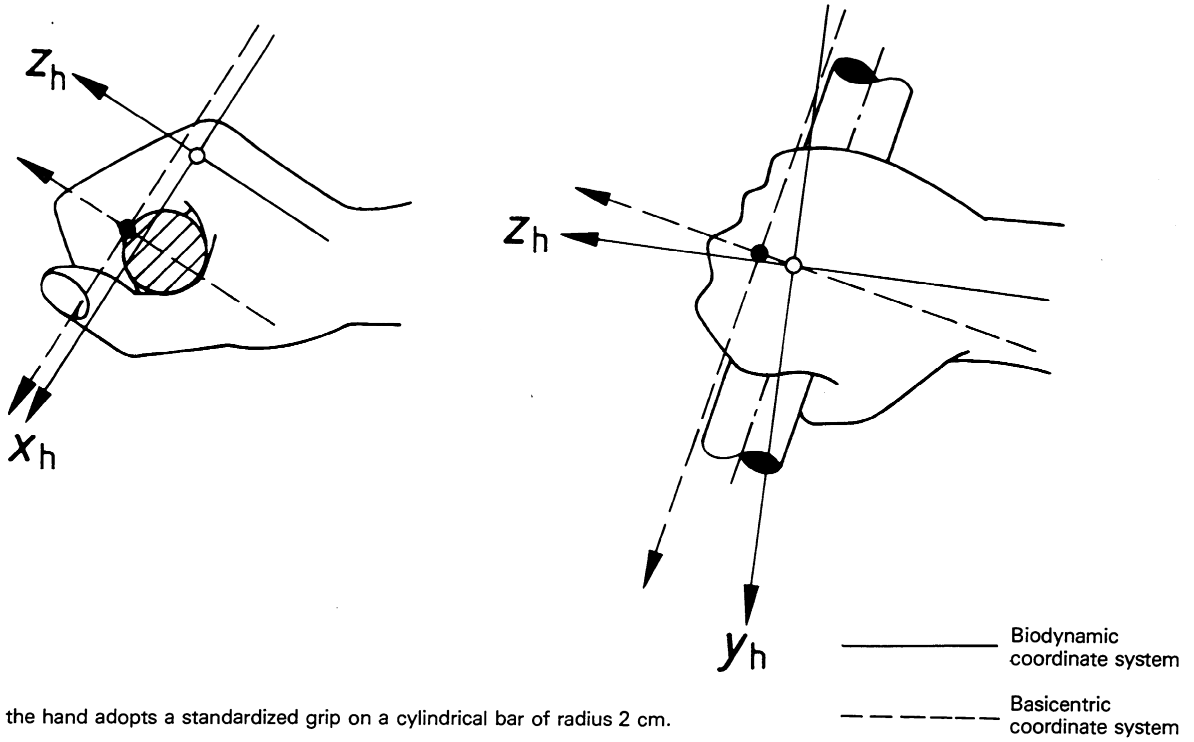
$$L_{\mathrm{h}} = 20 \lg \left(\frac{a}{a_{\mathrm{o}}} \right)$$

where

a is the r.m.s. acceleration, in metres per second squared;

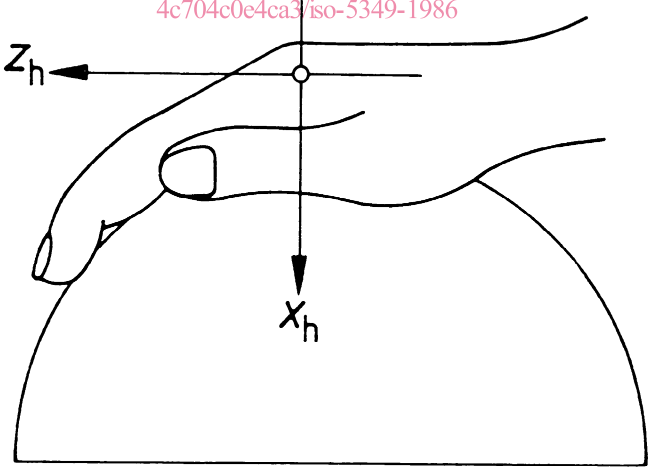
a_{o} is the reference acceleration of 1 µm/s^2.

The acceleration level may also be measured with the weighting network described in 3.4.5 and table 1 and is called the weighted acceleration level $L_{\mathrm{h,\,w}}$ (see 4.4). Acceleration levels measured in conjunction with frequency analysis equipment (for example one-third octave band filters) should not be weighted.



In this position, the hand adopts a standardized grip on a cylindrical bar of radius 2 cm.

a) "Handgrip" position



In this position, the hand presses down onto a sphere of radius 10 cm.

b) "Flat palm" position

NOTE — The origin of the system is deemed to lie in the head of the third metacarpal and the $z_{(hand)}$-axis to be defined by the longitudinal axis of that bone.

The x-axis is perpendicular to the palm area, being positive in the direction of the back of the palm, when the hand is in the normal anatomical position (palm facing forwards). The y-axis passes through the origin and is perpendicular to the x-axis.

When the hand is gripping a cylindrical handle, the system may be rotated so that the y_h-axis is parallel to the axis of the handle.

Figure 1 — Coordinate system for the hand

Table 1 — Frequency weighting filter for hand-arm vibration measurements

[Weighting factors to be applied in accordance with equations (4) and (7)]

Frequency Hz	Nominal gain dB
6,3	0
8,0	0
10,0	0
12,5	0
16	0
20	−2
25	−4
31,5	−6
40	−8
50	−10
63	−12
80	−14
100	−16
125	−18
160	−20
200	−22
250	−24
315	−26
400	−28
500	−30
630	−32
800	−34
1 000	−36
1 250	−38

3.4 Measurement of hand-transmitted vibration

3.4.1 Measuring equipment

Vibration-measuring equipment generally consists of a transducer, an amplifying device and amplitude or level indicator or recorder. Where practicable and appropriate, electronic networks may be included to limit the frequency range of the equipment. For many applications, where it is not essential to rely solely upon on-the-spot determination, a suitable recorder may be used to obtain representative records for subsequent analysis. An r.m.s.-measuring device may also be included for convenience, so that r.m.s. values may be read off or recorded directly.

All vibration-measuring equipment should be correctly calibrated and, whenever appropriate, calibrated in accordance with existing standards or recommendations governing the calibration of such equipment. The basis of operation and the characteristics of any measuring equipment used should be reported, together with the results obtained. It is important to report such characteristics as the frequency response, the dynamic properties (for example, the time constant, the dynamic range and resolution of the equipment), and when appropriate, the precision of r.m.s.-rectifying, tape recording, frequency analysis or similar operations performed upon the signal.

The dynamic range of the complete system should be as large as possible over the frequency range in question. It may be necessary to attenuate signals above 2 000 Hz; this attenuation should be made as near to the transducer as possible in the vibration measurement chain.

3.4.2 Measurement of r.m.s. value

If the signal for analysis is of short duration, or its magnitude varies substantially with time, a simple analysis cannot be made.

In order to obtain r.m.s. values under these circumstances, it is necessary to use an integrating meter or analyser which is equipped with "linear integration" facilities. It is recommended that "linear integration" analysis be adopted as a preferred method and only when the signal is relatively steady with time or of sufficient duration can use be made of the type of analyser normally used for noise analysis. In such circumstances, the time constant chosen should be appropriate for the signal duration.

3.4.3 Frequency range and transducer accuracy

The frequency range of measurement shall be at least 5 to 1 500 Hz, that is sufficient to cover the octave bands with centre frequencies from 8 to 1 000 Hz.

The vibration transducer shall be small and light enough for the specific application (see 3.4.4).

3.4.4 Location and mounting of vibration transducers

The measurements in the three axes shall be made on the surface of the hand(s) in the areas, or in clearly related areas, where the energy enters the body. If the person's hand is in direct contact with the vibrating surface of the hand grip, the transducer should be fastened to the vibrating structure. If the magnitude of vibration varies significantly over different parts of the handle, then the maximum value at a point in contact with the hand should be recorded. If a resilient element is being used between the hand and the vibrating structure (for example, a cushioned handle), it is permissible to use a suitable mount for the transducer (for example, a thin, suitably shaped metal sheet) placed between the hand and the surface of the resilient material. In any case, care shall be taken that the mass, size, shape and mounting of the transducer, or the special transducer support, do not significantly influence the transfer of vibration to the hand in the relevant frequency range.

NOTES

1 Standards for the measurement of vibration of specific tools should be used in conjunction with this International Standard. Specific standards may define more precise positions for mounting accelerometers and locating the origin of coordinates on specific tools.

2 For signals with very high peak accelerations, for example those obtained from percussive tools, special precautions should be taken to avoid errors which arise from overloading any part of the measurement system. Correct choice of the transducer is essential in this case. The transducer should be able to withstand the range of vibration measured, offer good stability and be small in size. It should have a resonant frequency above 25 kHz and have a cross-axis sensitivity at least 20 dB below the sensitivity in the axis to be measured. The preferred method of measurement involves inserting a mechanical low-pass filter with a suitably calibrated linear transfer function between the transducer and the vibrating surface. This will reduce peak values caused by high frequency components of the signal, that is those components above about 3 000 Hz.

3 In the case of a resilient element between the hand and the vibrating structure, the proposed method is not satisfactory for all conditions, particularly in the case of thin cushions which mainly affect the

transfer of higher frequencies. In such cases, it might be preferable to make the measurements with the transducer rigidly attached to the handle or structure and to record separately the type, thickness, physical properties and estimated attenuation achieved by the cushioning material.

3.4.5 Quantities to be measured

The acceleration measured in one or several axes can be reported either as a frequency-weighted acceleration or in terms of acceleration analysed in octave or one-third octave bands. For research and development purposes and to improve knowledge of the dose-response relationship, it is strongly recommended that one-third octave band data be obtained for each acceleration component.

The measurement of weighted acceleration shall be based on a weighting network which conforms with the characteristics defined in table 1.

The one-third octave band and octave band filters used in any analysing network shall be in accordance with IEC Publication 225. The frequency range given in IEC Publication 225 shall be extrapolated to lower frequencies.

3.4.6 Coupling of the hand to the vibration source

Although characterization of the vibration exposure currently uses the acceleration of the surface in contact with the hand as the primary quantity, it is reasonable to assume that the biological effects might depend, to a large extent, on the energy transmitted. This energy depends on the coupling of the hand-arm system to the vibration source and, consequently, on the grip pressure applied and the magnitude and direction of the static force. Measurement of the energy transmitted to the hand and of the tool application force is feasible and desirable for research purposes and for future application to special tools, but is not yet proposed in this International Standard.

For the purposes of this International Standard, the vibration exposure shall be reported for a grip pressure and static force, representative of the operational application of the tool or coupling of the hand to the vibration machinery. It should be borne in mind that changes in coupling can considerably affect the vibration exposure measured.

3.4.7 Exposure conditions and exposure time

Exposure intensity and the frequency spectrum transmitted will vary according to the individual's task, operating techniques, strength, weight and stamina. It is important, therefore, to base estimates of total daily exposure times on appropriate, representative samples for the various operating conditions and times and their intermittency. The posture of the hand and arm, or the angles of the wrist, elbow and shoulder joints shall always be reported for individual conditions and/or operating procedures.

4 Characterization of hand-transmitted vibration exposure

4.1 Daily exposure

The assessment of vibration exposure is primarily based on the daily exposure. The total time during which vibration is transmitted to the hands during a typical 8 h daily working period is not believed to have exceeded 4 h in any of the studies which have been used to develop the dose-effect relationship shown in annex A. This period of 4 h is, therefore, used as a basis for assessment.

In order to facilitate comparisons between different durations of exposure, the daily exposure is expressed here in terms of the energy-equivalent frequency-weighted acceleration for a period of 4 h.

If the total daily exposure to vibration is other than 4 h, then the energy-equivalent acceleration for a period of 4 h shall be determined by the integration of the square of the frequency-weighted acceleration over the whole of the daily exposure. This is expressed in equation (1)

$$(a_{h,w})_{eq(4)} = \left[\frac{1}{T_4} \int_0^{\tau} [a_{h,w}(t)]^2 \, dt \right]^{1/2} \qquad \ldots (1)$$

where

$(a_{h,w})_{eq(4)}$ is the energy equivalent acceleration for a period of 4 h;

$a_{h,w}(t)$ is the instantaneous value of the weighted acceleration;

τ is the total duration of the working day, in hours;

$T_4 = 4$ h.

NOTE — Although 4 h is used in this International Standard as a basis for the determination of energy equivalent acceleration, other periods of time, e.g. 8 h, could be used providing suitable mathematical modifications are made to the appropriate equations and tables.

4.1.1 If the energy equivalent acceleration is measured over a period of other than 4 h, then the energy-equivalent acceleration for a period of 4 h can be determined from equation (2)

$$(a_{h,w})_{eq(4)} = \left(\frac{T}{T_4} \right)^{1/2} (a_{h,w})_{eq(T)} \qquad \ldots (2)$$

where $(a_{h,w})_{eq(T)}$ is the frequency-weighted energy equivalent acceleration for a period of T h.

Example:

If $(a_{h,w})_{eq(6)} = 10 \text{ m} \cdot \text{s}^{-2}$

then $(a_{h,w})_{eq(4)} = (1{,}5)^{1/2} \times 10$

$= 12{,}25 \text{ m} \cdot \text{s}^{-2}$

4.1.2 If the operation is such that the total daily exposure comprises several exposures at different frequency-weighted accelerations, then the total frequency-weighted acceleration may be obtained from equation (3)

$$(a_{h,w})_{eq(T)} = \left\{ \frac{1}{T} \sum_{i=1}^{n} [(a_{h,w})_{eq(t_i)}]^2 t_i \right\}^{1/2} \qquad \ldots (3)$$

where $T = \sum_{i=1}^{n} t_i$

In equation (3), $(a_{h,w})_{eq(t_i)}$ is the frequency-weighted energy equivalent acceleration for the ith exposure component of duration t_i, in hours. T is the total duration of all the exposures. If T is not equal to 4 h, then equation (2) shall also be used to assess the compound exposure. It is recommended that the individual contributions to $(a_{h,w})_{eq(T)}$ be reported separately.

Example:

If the frequency-weighted accelerations for exposure times of 1, 3 and 5 h are respectively 15, 12 and 10 $m \cdot s^{-2}$, then

$$(a_{h,w})_{eq(9)} = \left[\frac{15^2 \times 1 + 12^2 \times 3 + 10^2 \times 5}{9} \right]^{1/2}$$

$$= 11{,}34 \ m \cdot s^{-2}$$

4.1.3 This method of evaluation may also be applied to one-third octave and octave band data.

4.2 Multi-axis vibration

It is recommended that the vibration be investigated in each of the three coordinate axes and that the assessment be based upon the component with the largest vibration acceleration.

NOTE — Dose-response relationships have been studied for industrial vibration exposure which involves complex three-dimensional acceleration. Characterization of the vibration exposure through the largest single component is generally regarded as adequate.

4.3 Conversion of one-third and octave band data to weighted acceleration

In order to use the dose-response relationships given in annex A, the results from one-third octave and octave band analysis can be used to estimate the corresponding weighted acceleration magnitude.

The weighted acceleration $a_{h,w}$ can be calculated from equation (4)

$$a_{h,w} = \sqrt{\sum_{j=1}^{n} (K_j a_{h,j})^2} \qquad \ldots (4)$$

where

K_j is the weighting factor for the jth one-third octave band or octave band given respectively in tables 2 and 3;

$a_{h,j}$ is the acceleration measured in the jth one-third octave band or octave band;

n is the number of one-third octave or octave bands being used.

NOTES

1 If the spectrum contains dominant single frequency components, the procedure outlined above may cause differences between the computed and directly measured values of the weighted acceleration. Discrepancies occur if the components are at frequencies which differ from the centre frequency of the one-third octave or octave band.

2 Instrumentation is available for measuring the frequency-weighted component acceleration directly.

4.4 Vibration acceleration level

Equations corresponding to equations (2) and (3) when using acceleration level to describe the vibration would become

$$(L_{h,w})_{eq(4)} = (L_{h,w})_{eq(T)} + 10 \lg \frac{T}{4} \qquad \ldots (5)$$

and

$$(L_{h,w})_{eq(T)} = 10 \lg \left\{ \frac{1}{T} \sum_{i=1}^{n} \left[10^{\frac{1}{10}(L_{h,w})_{eq(t_i)}} t_i \right] \right\} \ldots (6)$$

The example given in 4.1.1 would now become

If $(L_{h,w})_{eq(6)} = 140$ dB

then $(L_{h,w})_{eq(4)} = 140 + 10 \lg \frac{6}{4}$

$= 142$ dB

The example given in 4.1.2 would now become

If the weighted acceleration levels for exposure times of 1, 3 and 5 h are 143,5, 141,5 and 140 dB, then

$$(L_{h,w})_{eq(9)} = 10 \lg \frac{1}{9} \left[10^{14,35} + (10^{14,15} \times 3) + (10^{14} \times 5) \right]$$

$$= 141 \text{ dB}$$

The equation for the determination of the frequency-weighted acceleration level, which corresponds to equation (4) in 4.3, would become

$$L_{h,w} = 20 \lg \sqrt{\sum_{j=1}^{n} \left(K_j \times 10^{\frac{L_{h,j}}{20}} \right)^2} \qquad \ldots (7)$$

where

$L_{h,j}$ is the acceleration level measured in the jth one-third octave band or octave band;

K_j and n have the same meaning as in 4.3.

Table 2 — Values of K_j for conversion of one-third octave band measurements to weighted measurements

[Weighting factors to be applied in accordance with equations (4) and (7)]

Frequency Hz	Weighting factor (K_j)
6,3	1,0
8,0	1,0
10,0	1,0
12,5	1,0
16	1,0
20	0,8
25	0,63
31,5	0,5
40	0,4
50	0,3
63	0,25
80	0,2
100	0,16
125	0,125
160	0,1
200	0,08
250	0,063
315	0,05
400	0,04
500	0,03
630	0,025
800	0,02
1 000	0,016
1 250	0,012 5

Table 3 — Values of K_j for conversion of octave band measurements to weighted measurements

[Weighting factors to be applied in accordance with equations (4) and (7)]

Frequency Hz	Weighting factor (K_j)
8,0	1,0
16,0	1,0
31,5	0,5
63	0,25
125	0,125
250	0,063
500	0,03
1 000	0,016