IS/ISO 5349-1 (2001): Mechanical Vibration - Measurement and and Evaluation of Human Exposure to Hand Transmitted Vibration, Part 1: General Requirements [MED 28: Mechanical Vibration and Shock]

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भारतीय मानक

यॉँत्रिक कंपन — हस्त-संचरित कंपन का मानव पर प्रभाव का मापन और मूल्यांकन

भाग 1 सामान्य अपेक्षाएँ

(पहला पुनरीक्षण)

Indian Standard

MECHANICAL VIBRATION — MEASUREMENT AND EVALUATION OF HUMAN EXPOSURE TO HAND-TRANSMITTED VIBRATION

PART 1 GENERAL REQUIREMENTS

(First Revision)

ICS 13.160

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NATIONAL FOREWORD

This Indian Standard (Part 1) (First Revision) which is identical with ISO 5349-1 : 2001 'Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 1: General requirements' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Mechanical Vibration and Shock Sectional Committee and approval of the Mechanical Engineering Division Council.

This standard was first published as IS/ISO 5349 : 1986. Due to technical changes in ISO Standard, this standard also revised in two parts. Other part is as under:

Part 2 Practical guidance for measurement at the workplace

The text of ISO Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker in the International Standards, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 2041 : 1990 Vibration and shock — Vocabulary	IS 11717 : 2000 Vocabulary on vibration and shock (*first revision*)	Identical
ISO 5349-2 : 2001 Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration — Part 2: Practical guidance for measurement at the workplace	IS/ISO 5349-2 : 2001 Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration: Part 2 Practical guidance for measurement at the workplace	do
ISO 8041 : 2005 Human response to vibration — Measuring instrumentation	IS/ISO 8041 : 2005 Human response to vibration — Measuring instrumentation	do

The technical committee responsible for the preparation of this standard has reviewed the provisions of the following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard.

International Standard	*Title*
IEC 61260 : 1995	Electro-acoustics — Octave-band and fractional-octave-band filters

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

MECHANICAL VIBRATION — MEASUREMENT AND EVALUATION OF HUMAN EXPOSURE TO HAND-TRANSMITTED VIBRATION

PART 1 GENERAL REQUIREMENTS

(First Revision)

1 Scope

This part of ISO 5349 specifies general requirements for measuring and reporting hand-transmitted vibration exposure in three orthogonal axes. It defines a frequency weighting and band-limiting filters to allow uniform comparison of measurements. The values obtained can be used to predict adverse effects of hand-transmitted vibration over the frequency range covered by the octave bands from 8 Hz to 1 000 Hz.

This part of ISO 5349 is applicable to periodic and to random or non-periodic vibration. Provisionally, this part of ISO 5349 is also applicable to repeated shock type excitation (impact).

NOTE 1 The time dependency for human response to repeated shocks is not fully known. Application of this part of ISO 5349 for such vibration is to be made with caution.

This part of ISO 5349 provides guidance for the evaluation of hand-transmitted vibration exposure, specified in terms of a frequency-weighted vibration acceleration and daily exposure time. It does not define limits of safe vibration exposure.

NOTE 2 Annex C is concerned with the approximate relative importance of various characteristics of the vibration exposure which are believed to produce health effects.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 5349. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 5349 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2041, *Vibration and shock — Vocabulary.*

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 8041, *Human response to vibration — Measuring instrumentation.*

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

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this part of ISO 5349, the terms and definitions given in ISO 2041 apply.

NOTE For the convenience of users of this part of ISO 5349, a glossary of terms relating to medical conditions is given in annex B.

3.2 Symbols

In this part of ISO 5349, the following symbols are used.

$a_{hw}(t)$ instantaneous single-axis acceleration value of the frequency-weighted hand-transmitted vibration at time t, in metres per second squared (m/s^2);

a_{hw} root-mean-square (r.m.s.) single-axis acceleration value of the frequency-weighted hand-transmitted vibration, in metres per second squared (m/s^2);

a_{hwx}, a_{hwy}, a_{hwz} values of a_{hw}, in metres per second squared (m/s^2), for the axes denoted x, y and z respectively;

a_{hv} vibration total value of frequency-weighted r.m.s. acceleration (sometimes known as the vector sum or the frequency-weighted acceleration sum); it is the root-sum-of-squares of the a_{hw} values for the three measured axes of vibration, in metres per second squared (m/s^2);

$a_{hv(eq,8h)}$ daily vibration exposure (8-h energy-equivalent vibration total value), in metres per second squared (m/s^2);

$A(8)$ a convenient alternative term for the daily vibration exposure $a_{hv(eq,8h)}$;

D_y group mean total (lifetime) exposure duration, in years;

T total daily duration of exposure to the vibration a_{hv};

T_0 reference duration of 8 h (28 800 s);

W_h frequency-weighting characteristic for hand-transmitted vibration.

4 Characterization of hand-transmitted vibration

4.1 General considerations

The method specified in this part of ISO 5349 takes account of the following factors which are known to influence the 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;

d) the cumulative exposure to date.

Other factors which may influence the effects of vibration exposure, but for which standardized methods for reporting do not yet exist, are listed in annex D.

4.2 Measuring equipment for hand-transmitted vibration

4.2.1 General

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

4.2.2 Vibration transducers

The vibration transducer may be an accelerometer which may be designed to make general vibration measurements (for non-percussive tools) or may be specifically designed for large peak accelerations such as those produced by percussive tools.

The vibration transducers shall be able to withstand the range of vibration magnitudes and shall have stable characteristics. The dimensions of the transducers shall be such that they do not interfere with the operation of the machine and such that the location of the point of measurement can be identified.

ISO 5349-2 contains further guidance on the selection of transducers.

4.2.3 Location and orientation of transducers

The vibration transmitted to the hand shall be measured and reported for three directions of an orthogonal coordinate system such as defined in Figure 1.

For practical vibration measurements, the orientation of the coordinate system may be defined with reference to an appropriate basicentric coordinate system (see Figure 1) originating, for example, in a vibrating appliance, workpiece, handle or control device gripped by the hand (see ISO 8727 for further information).

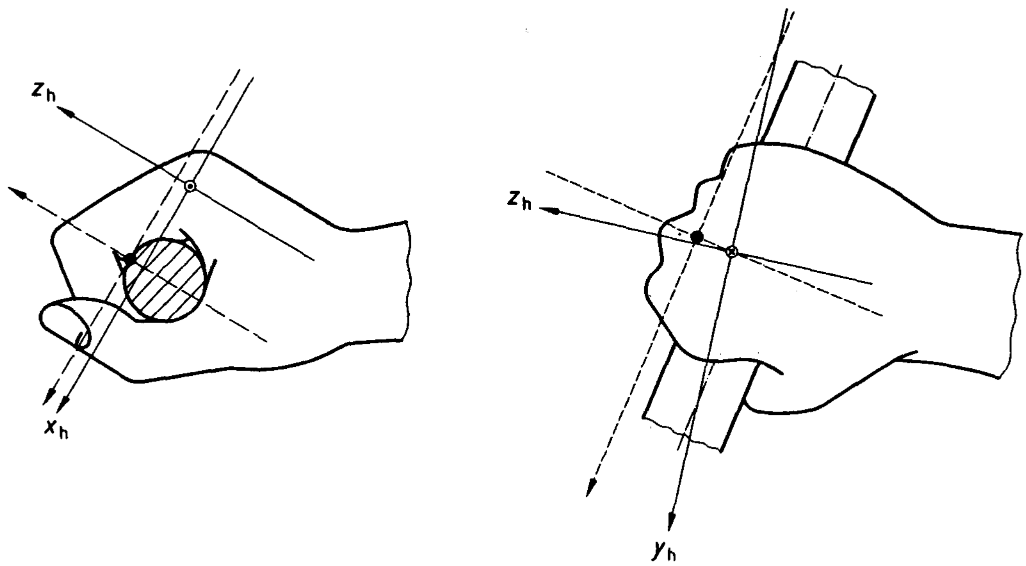
The vibration in the three directions should preferably be measured simultaneously. Measurements made sequentially along each of the three axes are acceptable, provided the operating conditions are similar for all three measurements. The measurements shall be made on the vibrating surface as close as possible to the centre of the gripping zone of the machine, tool or workpiece. The location of the transducers shall be reported.

NOTE The vibration magnitude can vary considerably with position on the vibrating surface.

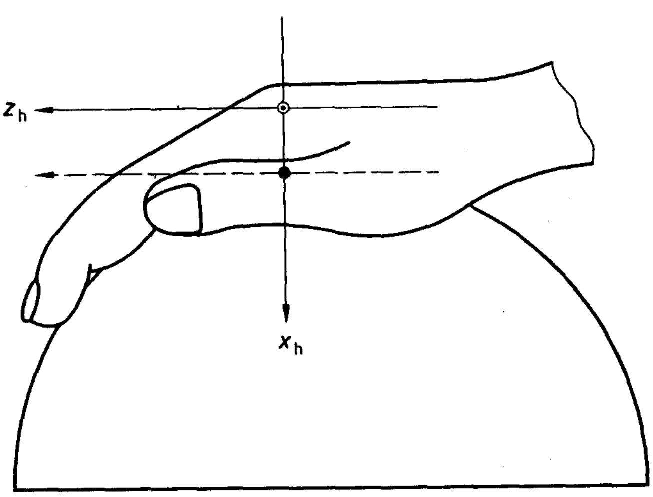
Further guidance on transducer positioning is given in ISO 5349-2.

4.2.4 Mounting of transducers

The transducers should be mounted rigidly. Further information on accelerometer mounting is given in ISO 5348 and ISO 5349-2. Practical guidance on mounting transducers in difficult situations (such as on resilient surfaces or where the vibration is impulsive), and on the use of hand-held adaptors, is also given in ISO 5349-2.



a) "Handgrip" position (In this position, the hand adopts a standardized grip on a cylindrical bar)



Key

————————	Biodynamic coordinate system
----------------	Basicentric coordinate system

b) "Flat palm" position (In this position, the hand presses down onto a sphere)

NOTE The origin of the biodynamic coordinate system is the head of the third metacarpal (distal extremity). The z_h-axis (i.e. hand axis) is defined as the longitudinal axis of the third metacarpal bone and is oriented positively towards the distal end of the finger. The x_h-axis passes through the origin, is perpendicular to the z_h-axis, and is positive in the forwards direction when the hand is in the normal anatomical position (palm facing forwards). The y_h-axis is perpendicular to the other two axes and is positive in the direction towards the fifth finger (thumb). In practice, the basicentric coordinate system is used: the system is generally rotated in the y-z plane so that the y_h-axis is parallel to the handle axis.

Figure 1 — Coordinate systems for the hand

4.3 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 depend to a large extent on the coupling of the hand to the vibration source. It should also be noted that the coupling can affect considerably the vibration magnitudes measured.

The vibration measurements shall be made with forces which are representative of the coupling of the hand to the vibrating power tool, handle or workpiece in typical operation of the tool or process.

. orces between the hand and gripping zone should be measured and reported.[1)] It is also recommended that a description of the operator's posture be reported for individual conditions and/or operating procedures (see annexes D and F).

4.4 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_h reflects the assumed importance of different frequencies in causing injury to the hand. The characteristics of the W_h frequency weighting and methods for band-limiting are given in annex A.

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

For additional purposes (research, prevention, technical reduction of vibration) it is strongly recommended that frequency spectra be obtained (see annex F for further information).

4.5 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_{hwx}, a_{hwy} and a_{hwz}, shall be reported separately (see annex F).

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_{hv}, and is defined as the root-sum-of-squares of the three component values:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (1)$$

In some cases it may not be possible to make vibration measurements in three axes. If measurements are made only in one or two axes, the axis of greatest vibration shall be included (where this can be identified). The vibration total value shall be estimated using the measured values available and a carefully considered multiplying factor. The vibration magnitude in the axis of greatest vibration requires a multiplying factor in the range 1,0 to 1,7 to give the vibration total value (for further advice, see ISO 5349-2). Where a multiplying factor is used to estimate the vibration total value, the multiplying factor and a justification for the choice of value shall be reported, together with the component value(s) measured.

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1) An International Standard on the measurement of gripping and pushing forces is in course of preparation.

5 Characterization of hand-transmitted vibration exposure

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 health effects given in annex C, the vibration magnitude is represented by the vibration total value a_{hv}.

5.2 Daily exposure duration

Daily exposure duration is the total time for which the hand(s) is(are) exposed to vibration during the working day. The vibration exposure time may be shorter than the time for which the person is working with the power tools or workpieces. It is important to base estimates of total daily exposure duration on appropriate representative samples for the various operating conditions and durations and their intermittency (see ISO 5349-2 for further guidance).

5.3 Daily vibration exposure

Daily vibration exposure is derived from the magnitude of the vibration (vibration total value) and the daily exposure duration.

In order to facilitate comparisons between daily exposures of different durations, the daily vibration exposure shall be expressed in terms of the 8-h energy-equivalent frequency-weighted vibration total value, $a_{hv(eq,8h)}$, as shown in equation (2). For convenience, $a_{hv(eq,8h)}$ is denoted $A(8)$:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \tag{2}$$

where

T is the total daily duration of exposure to the vibration a_{hv};

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

If the work is such that the total daily vibration exposure consists of several operations with different vibration magnitudes, then the daily vibration exposure, $A(8)$, shall be obtained using equation (3):

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{hvi}^2 T_i} \tag{3}$$

where

a_{hvi} 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.

The individual contributions to $A(8)$ shall be reported separately.

EXAMPLE If the vibration total values for exposure times of 1 h, 3 h and 0,5 h (within the same working day) are 2 m/s^2, 3,5 m/s^2 and 10 m/s^2 respectively, then:

$$A(8) = \sqrt{\frac{1}{8\ \text{h}}\left[\left(2\ \text{m/s}^2\right)^2 \times 1\ \text{h} + \left(3{,}5\ \text{m/s}^2\right)^2 \times 3\ \text{h} + \left(10\ \text{m/s}^2\right)^2 \times 0{,}5\ \text{h}\right]} = 3{,}4\ \text{m/s}^2$$

NOTE The result of the calculation in the above example is quoted to two significant figures. This does not imply an equivalent accuracy of measurement but arises from the computation. In normal measuring situations it would require great care to obtain an accuracy better than 10 % in the value of $A(8)$.

It is recommended that, where criteria for acceptable vibration exposures are to be defined, these should be specified as $A(8)$ values.

6 Information to be reported

When an evaluation of exposure to hand-transmitted vibration is carried out in accordance with this part of ISO 5349, the following information shall be reported:

— the subject of the exposure evaluation;

— the operations causing exposures to vibration;

— the power tools, inserted tools and/or workpieces involved;

— the location and orientation of the transducers;

— the individual root-mean-square, single-axis frequency-weighted accelerations measured;

— the vibration total value for each operation;

— the total daily duration for each operation;

— the daily vibration exposure.

Where measurements have not been made in all three axes, the multiplying factor used to estimate the vibration total value, and the justification for its selection, shall also be reported.

NOTE In ISO 5349-2, a more exhaustive list of recommended information to be reported is given (see also annexes D and F).

Annex A
(normative)

Frequency-weighting and band-limiting filters

A.1 Frequency-weighting and band-limiting filter characteristics

The measurement of a_{hw} requires the application of frequency-weighting and band-limiting filters. The frequency weighting W_h reflects the assumed importance of different frequencies in causing injury to the hand. The range of application of the measured values to the prediction of vibration injury (see annex C) is restricted to the working frequency range covered by the octave bands from 8 Hz to 1 000 Hz (i.e. a nominal frequency range from 5,6 Hz to 1 400 Hz). Band-limiting high-pass and low-pass filters restrict the effect on the measured value of vibration frequencies outside this range where the frequency dependence is not yet agreed.

NOTE The frequency dependencies of responses to vibration are unlikely to be the same in all axes. However, it is not yet thought appropriate to recommend different frequency weightings for different axes.

The frequency-weighting and band-limiting filters may be realized by analog or digital methods. They are defined in Table A.1 in a mathematical form familiar to filter designers and the curve is shown graphically in Figure A.1 in a schematic way. Further details and tolerances for filter characteristics are given in ISO 8041.

Table A.1 — Characteristics of band-limiting and weighting filters for the frequency weighting W_h

Band limiting[a]			Frequency weighting[a]			
f_1	f_2	Q_1	f_3	f_4	Q_2	K
6,310	1258,9	0,71	15,915	15,915	0,64	1

The band-limiting filter is defined by the transfer function of the filter, $H_b(s)$:

$$H_b(s) = \frac{s^2 4\pi^2 f_2^2}{(s^2 + 2\pi f_1 s / Q_1 + 4\pi^2 f_1^2)(s^2 + 2\pi f_2 s / Q_1 + 4\pi^2 f_2^2)}$$

where $s = j2\pi f$ is the variable of the Laplace transform.

The band-limiting filter can be realized by a two-pole filter.

The frequency-weighting filter is defined by the transfer function of the filter, $H_w(s)$:

$$H_w(s) = \frac{(s + 2\pi f_3)\, 2\pi K f_4^2}{(s^2 + 2\pi f_4 s / Q_2 + 4\pi^2 f_4^2) f_3}$$

where $s = j2\pi f$ is the variable of the Laplace transform.

The frequency-weighting filter can be realized by a two-pole filter.

The total frequency-weighting function is $H(s) = H_b(s) \cdot H_w(s)$.

[a] Values of f_n designate resonance frequencies (n = 1 to 4); Q_n designate selectivity (n = 1 or 2); K is a constant gain.

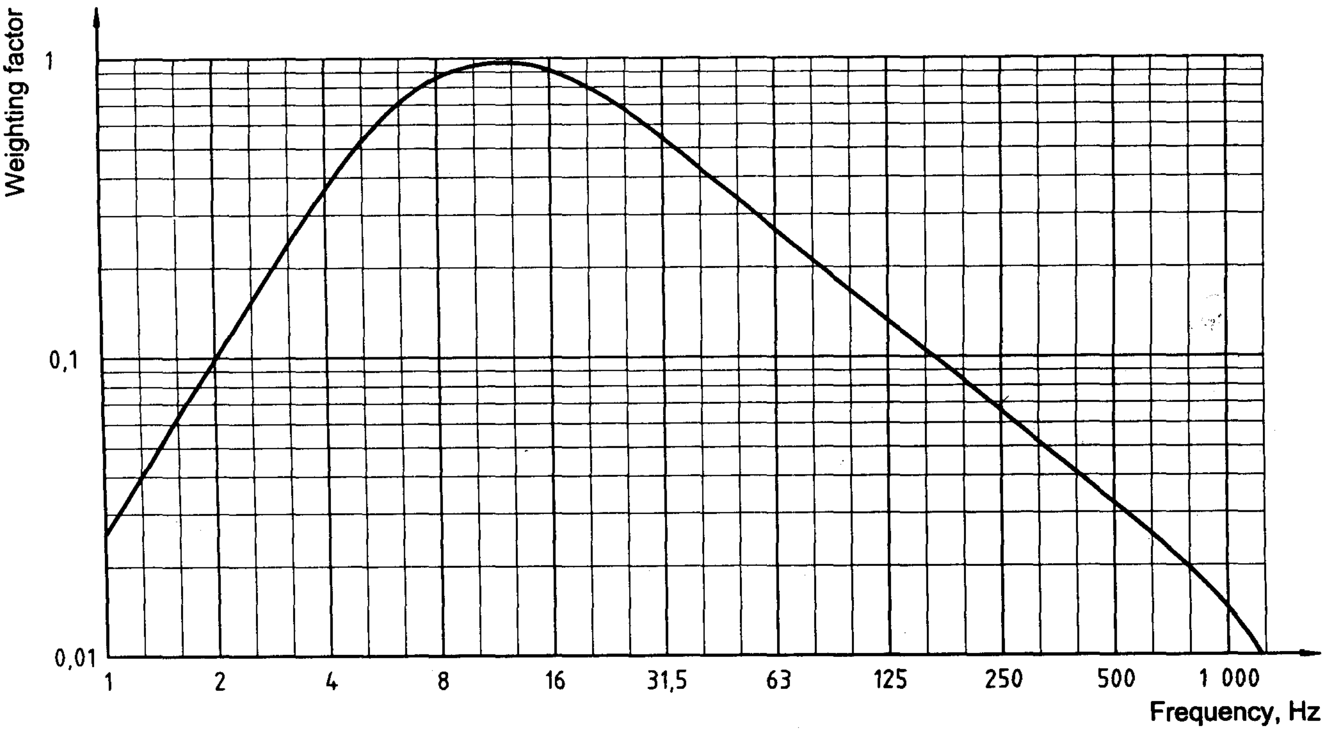

Figure A.1 — Frequency-weighting curve W_h for hand-transmitted vibration, band-limiting included (schematic)

A.2 Conversion of one-third-octave band data to frequency-weighted acceleration

As an alternative to the use of the W_h filter, the r.m.s. acceleration values from one-third-octave band analysis can be used to obtain the corresponding frequency-weighted acceleration.

The r.m.s. frequency-weighted acceleration a_{hw} can be calculated as follows:

$$a_{hw} = \sqrt{\sum_i (W_{hi} a_{hi})^2} \qquad \text{(A.1)}$$

where

W_{hi} is the weighting factor for the i th one-third-octave band as shown in Table A.2;

a_{hi} is the r.m.s. acceleration measured in the i th one-third-octave band, in metres per second squared (m/s^2).

The one-third-octave band frequencies from 6,3 Hz to 1 250 Hz constitute the primary frequency range and the calculation of a_{hw} using equation (A.1) shall include all one-third-octave bands within this range. Frequencies outside this primary range (i.e. those shown in the grey areas of Table A.2) do not generally make an important contribution to the value of a_{hw} and may be excluded from the calculation, provided it is known that there is no significant vibration energy at the high and low ends of the frequency range.

If the frequency-weighted acceleration value is influenced by significant components at the high and low ends of the frequency range, the guidance in annex C for the prediction of finger blanching from vibration exposure data should be treated with caution.

NOTE If the spectrum contains dominant single-frequency components, the procedure outlined above may cause differences between the computed and directly measured values of the frequency-weighted acceleration. Discrepancies occur if these components are at frequencies which differ from the centre frequency of a one-third-octave band. For this reason, the use of the weighting filter W_h or calculations based on narrower band measurements are preferred. When, in the latter case, for a certain frequency f or a narrow frequency band with the mid-frequency f the unweighted vibration acceleration $a(f)$ is given, the corresponding weighted acceleration $a_h(f)$ is calculated to be $a_h(f) = a(f)\,|H(j2\pi f)|$.

Table A.2 — Frequency weighting factors W_{hi} for hand-transmitted vibration with band limiting[a] for conversion of one-third-octave band magnitudes to frequency-weighted magnitudes

Frequency band number[b] i	Nominal mid frequency Hz	Weighting factor W_{hi}
6	4	0,375
7	5	0,545
8	6,3	0,727
9	8	0,873
10	10	0,951
11	12,5	0,958
12	16	0,896
13	20	0,782
14	25	0,647
15	31,5	0,519
16	40	0,411
17	50	0,324
18	63	0,256
19	80	0,202
20	100	0,160
21	125	0,127
22	160	0,101
23	200	0,0799
24	250	0,0634
25	315	0,0503
26	400	0,0398
27	500	0,0314
28	630	0,0245
29	800	0,0186
30	1 000	0,0135
31	1 250	0,00894
32	1 600	0,00536
33	2 000	0,00295

[a] *For filter responses and tolerances, see ISO 8041.*

[b] Index i is the frequency band number in accordance with IEC 61260.

Annex B
(informative)

Guidance on health effects of hand-transmitted vibration

B.1 General

Powered processes and tools which expose operators' hands to vibration are widespread in several industrial activities. Occupational exposure to hand-transmitted vibration can arise from rotating and/or percussive hand-held power tools used in the manufacturing industry, quarrying, mining and construction, forestry and agriculture, public utilities and other work activities. Exposure to hand-transmitted vibration can also occur from vibrating workpieces held in the hands of the operator, and from hand-held vibrating controls such as motorcycle handlebars or vehicle steering wheels.

Excessive exposure to hand-transmitted vibration can induce disturbances in finger blood flow, and in neurological and motor functions of the hand and arm. It has been estimated that 1,7 % to 3,6 % of the workers in the European countries and the USA are exposed to potentially harmful hand-transmitted vibration. The term "hand-arm vibration syndrome" (HAVS) is commonly used to refer to the complex of peripheral vascular, neurological and musculoskeletal disorders associated with exposure to hand-transmitted vibration. Workers exposed to hand-transmitted vibration may be affected with neurological and/or vascular disorders separately or simultaneously. Vascular disorders and bone and joint abnormalities caused by hand-transmitted vibration are compensated occupational diseases in several countries. These disorders are also included in an European list of recognized occupational diseases.

B.2 Vascular disorders

Workers exposed to hand-transmitted vibration may complain of episodes of pale or white finger, usually triggered by cold exposure. This disorder, due to temporary abolition of blood circulation to the fingers, is called Raynaud's phenomenon (after Maurice Raynaud, a French physician who first described it in 1862). It is believed that vibration can disturb the digital circulation making it more sensitive to the vasoconstrictive action of cold. To explain cold-induced Raynaud's phenomenon in vibration-exposed workers, some investigators invoke an exaggerated central vasoconstrictor reflex caused by prolonged exposure to harmful vibration, while others tend to emphasize the role of vibration-induced local changes in the digital vessels. Various synonyms have been used to describe vibration-induced vascular disorders: dead or white finger, Raynaud's phenomenon of occupational origin, traumatic vasospastic disease, and, more recently, vibration-induced white finger (VWF). VWF is a prescribed occupational disease in many countries.

Initially attacks of blanching involve the tips of one or more fingers but, with continued exposure to vibration, the blanching can extend to the base of the fingers. Sometimes, an attack of blanching is followed by cyanosis, i.e. a bluish discoloration of the affected fingers due to increased extraction of oxygen from the sluggish digital circulation. In the recovery phase, commonly accelerated by warmth or local massage, redness, eventually associated with tingling and/or pain, may appear in the affected fingers as a result of a reactive increase of blood flow in the cutaneous vessels. The blanching attacks are more common in winter than in summer and last from a few minutes to more than one hour. The duration varies with the intensity of the triggering stimuli and the severity of the vasospasm, the attack usually ending when the whole body is warmed. If vibration exposure continues, the blanching attacks become more frequent and may occur all year around. In the rare advanced cases, repeated and severe finger blanching attacks can lead to trophic changes (ulceration or gangrene) in the skin of the fingertips. During the attack the affected workers can experience a complete loss of touch sensation and manipulative dexterity, which can interfere with work activity, thus increasing the risk for acute injuries due to accidents.

In occupational medicine, various staging systems for the classification of VWF have been developed. The Stockholm Workshop Scale (1986) is an internationally recognized grading system for classifying cold-induced Raynaud's phenomenon in the hand-arm vibration syndrome. This scale consists of four stages according to the extent, frequency and severity of finger blanching attacks and is described in Table B.1. A scale based on scores for the blanching of different phalanges has also been proposed (see reference [13]).

Several laboratory tests are used to diagnose white finger objectively. Most of these tests are based on cold provocation and the measurement of finger skin temperature or digital blood flow and pressure before, during and after cooling of the fingers and hands.

Epidemiological studies have demonstrated that the prevalence of VWF varies widely, from 0 % to 100 % of individuals in a group of vibration-exposed workers. It appears that the probability and severity of white-finger symptoms is influenced by several factors, such as the characteristics of vibration exposure (frequency, magnitude, direction, impulsiveness, duration), the type of tool and work process, the environmental conditions (temperature, air flow, humidity, noise), some biodynamic and ergonomic factors (grip force, feed force, arm posture), and various individual characteristics (susceptibility, diseases and agents, e.g. nicotine and certain medicines, affecting the peripheral circulation). Thus, there is a complex relationship between vibration exposure and the development of white finger symptoms. Epidemiological studies suggest that the occurrence of VWF increases with increasing duration of vibration exposure. There is some evidence that the cumulative exposure before the appearance of finger blanching is approximately inversely proportional to the magnitude of the vibration exposure (i.e. if vibration magnitudes are doubled, a halving of the years of exposure is required to produce the same effect).

Since the late 1970s a decrease in the incidence of VWF has been reported among active forestry workers in both Europe and Japan after the introduction of anti-vibration chain saws and administrative measures curtailing the saw usage time together with endeavours to reduce exposure to other harmful work environment factors (e.g. cold and physical stress). Recovery from VWF has also been reported among retired forestry workers. Similar findings are not yet available for other tool types.

Table B.1 — Stockholm Workshop Scale (1986)

Vascular component		
Stage	**Grade**	**Description**
0	—	No attacks
1_V	Mild	Occasional attacks affecting only the tips of one or more fingers
2_V	Moderate	Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers
3_V	Severe	Frequent attacks affecting all phalanges of most fingers
4_V	Very severe	As in stage 3 with trophic changes in the fingertips

Sensorineural component	
Stage	**Description**
0_{SN}	Exposed to vibration but no symptoms
1_{SN}	Intermittent numbness with or without tingling
2_{SN}	Intermittent or persistent numbness, reduced sensory perception
3_{SN}	Intermittent or persistent numbness, reduced tactile discrimination and/or manipulative dexterity

B.3 Neurological disorders

Workers exposed to hand-transmitted vibration may experience tingling and numbness in their fingers and hands. If vibration exposure continues, these symptoms tend to worsen and can interfere with work capacity and life activities. Vibration-exposed workers may exhibit a reduction in the normal sense of touch and temperature as well as an impairment of manual dexterity at the clinical examination. As an other effect of hand-transmitted vibration, a reduction of the vibration sensitivity of the skin of the fingertips may also be found. Epidemiological surveys of vibration-exposed workers show that the prevalence of peripheral neurological disorders varies from a few percent to more than 80 % of individuals in a group of vibration-exposed workers, and that sensory loss affects users of a wide range of tool types.

It seems that sensorineural disturbances may develop independently of other vibration-induced disorders, probably reflecting different pathological mechanisms. A classification for the neurological component of the HAVS was proposed at the Stockholm Workshop 1986, consisting of three stages according to the symptoms complained and the results of clinical neurological examination and psychophysical testing methods such as tactile discrimination, vibrotactile perception and precision manipulation (see Table B.1).

Vibration-exposed workers may sometimes show signs and symptoms of entrapment neuropathies, such as carpal tunnel syndrome (CTS), a disorder due to compression of the median nerve as it passes through an anatomical tunnel in the wrist. CTS seems to occur in some occupational groups using vibrating tools such as rock-drillers, platers and forestry workers. It is believed that ergonomic stressors acting on the hand and wrist (repetitive movements, forceful gripping, awkward postures), in combination with vibration can cause CTS in workers handling vibrating tools.

B.4 Musculoskeletal disorders

B.4.1 Skeletal

Early radiological investigations revealed a high prevalence of bone vacuoles and cysts in the hands and wrists of vibration-exposed workers, but more recent studies have shown no significant increase with respect to manual workers not exposed to vibration. Excess occurrence of wrist and elbow osteoarthrosis as well as ossifications at the sites of tendon insertion, mostly at the elbow, have been found in miners, road construction workers and metal-working operators exposed to shock and low-frequency vibration (< 50 Hz) of high magnitude from pneumatic percussive tools.

An excess prevalence of Kienböck's disease (lunate malacia) and pseudoarthrosis of the scaphoid bone in the wrist has also been reported by a few investigators. There is little evidence of an increased prevalence of degenerative bone and joint disorders in the upper limbs of workers exposed to mid- or high-frequency vibration arising from chain saws or grinding operation. Heavy physical effort, forceful gripping and various biomechanical factors may account for the higher occurrence of skeletal injuries found in workers operating percussive tools. Local pain, swelling, and joint stiffness and deformities may be associated with radiological findings of bone and joint degeneration. In some countries (e.g. France, Germany, Italy), bone and joint disorders occurring in workers using hand-held vibrating tools are considered to be an occupational disease and the affected workers are compensated.

B.4.2 Muscular

Workers with prolonged exposure to vibration may complain of muscular weakness, pain in the hands and arms, and diminished muscle force. Vibration exposure has also been found to be associated with a reduction of hand-grip strength. In some individuals muscle fatigue can cause disability. Direct mechanical injury or peripheral nerve damage have been suggested as possible etiologic factors for such muscle symptoms.

Other work-related disorders have been reported in vibration-exposed workers, such as tendinitis and tenosynovitis (i.e. inflammation of tendons and their sheaths) in the upper limbs, and Dupuytren's contracture, a disease of the fascial tissues of the palm of the hand. These disorders seem to be related to ergonomic stress factors arising from heavy manual work, and the association with hand-transmitted vibration is not conclusive.

B.5 Other disorders

Some studies indicate that in workers affected with VWF, hearing loss is greater than that expected on the basis of ageing and noise exposure from vibrating tools. It has been suggested that VWF subjects may have an additional risk of hearing impairment due to vibration-induced vasoconstriction of the blood vessels supplying the inner ear. In addition to peripheral disorders, other adverse health effects involving the endocrine and central nervous system of vibration-exposed workers have been reported by Russian and Japanese investigators. The clinical picture, called "vibration disease", includes signs and symptoms related to dysfunction of the higher centres of the brain (e.g. persistent fatigue, headache, irritability, sleep disturbances, impotence, electroencephalographic abnormalities). These findings should be interpreted with caution and further carefully designed epidemiological and clinical research work is needed to confirm the hypothesis of an association between disorders of the central nervous system and exposure to hand-transmitted vibration.

B.6 Glossary

Bone cyst: an abnormal cavity in the bone structure.

Carpal tunnel syndrome: symptoms of numbness, tingling, or burning pain on the palmar surfaces of the thumb, index, middle and ring fingers, occurring mostly at night, caused by compression or irritation of the median nerve as it passes through a tunnel formed by the wrist (carpal) bones. Signs of impaired hand function and disability may develop.

Cyanosis: bluish discoloration of the skin or other tissues due to the presence of deoxygenated blood in the superficial capillaries.

Dupuytren's contracture: thickening of the fibrous lining of the palm of the hand preventing the straightening of the fingers, mainly the ring and little finger.

Epidemiology: study of the occurrence — prevalence and incidence — of diseases or disorders in a population. *Occupational epidemiology* investigates the relation between exposure to work risk factors and their possible adverse health effects.

Hand-arm vibration syndrome: complex symptoms and signs (neurological, vascular and musculoskeletal) associated with disorders produced by hand-transmitted vibration.

Kienböck's disease: disorder of mineralization (malacia) of the lunate bone in the wrist.

Incidence: number of new cases of a disease or disorder in a population over a specified period of time.

Osteoarthrosis: bone and joint degeneration.

Prevalence: number of existing cases of disease or disorder in a given population at a specified time.

Raynaud's phenomenon: attacks of finger blanching due to insufficient circulation of blood as a result of digital vasoconstriction usually triggered by cold or emotion. *Primary Raynaud's disease*, when the symptom of finger blanching cannot be attributed to any specific cause. *Secondary Raynaud's phenomenon*, when some causes can be identified. *Vibration-induced white finger,* a secondary form of Raynaud's phenomenon caused by exposure to hand-transmitted vibration.

Sensorineural disorders: abnormalities in the sensation of light touch, pain, temperature, vibration and deep pressure; impairment of discriminative sensory function (two-point discrimination, appreciation of texture, size and shape).

Tendinitis: inflammation of a tendon.

Tenosynovitis: inflammation of a tendon and its sheath.

Vasoconstriction: narrowing of the lumen of blood vessels, especially as a result of an increased contraction of the muscle wall of the blood vessel.

Annex C
(informative)

Relationship between vibration exposure and effects on health

C.1 Background to the method of assessment

This annex is concerned with the approximate relative importance of various characteristics of the vibration exposure which are believed to produce health effects. It does not define limits of safe vibration exposure.

The frequency weighting defined in this part of ISO 5349 is based on that in the previous version (ISO 5349:1986) and is believed to provide the best guidance available concerning the relative potential of different frequencies to produce vibration-related health effects in the hand and arm.

It is not known whether this frequency weighting represents, separately, the hazard of developing vascular, neurological or musculoskeletal disorders. At present, it is used for the assessment of **all** biological effects of hand-transmitted vibration.

It is assumed that vibration in each of the three directions defined by the orthogonal axes given in Figure 1 is equally detrimental, and that the same frequency weighting may be used for each axis. The injury potential of hand-transmitted vibration is therefore estimated from the vibration total value, a_{hv}, formed from the three frequency-weighted component (single-axis) accelerations at a surface in contact with the hand as defined in this part of ISO 5349.

It is assumed that the method given in this part of ISO 5349 for obtaining the 8-h energy-equivalent vibration total value appropriately reflects the relationship between different vibration magnitudes and daily exposure durations.

NOTE 1 This method assumes that the daily exposure time required to produce symptoms of the hand-arm vibration syndrome is inversely proportional to the square of the frequency-weighted acceleration. If, for example, the vibration magnitude is halved, then the daily exposure time can be increased by a factor of four for the same effect.

NOTE 2 There is a shortage of data relating daily exposure durations to health effects. The time dependency chosen is equivalent to a constant daily vibration energy.

NOTE 3 The time dependency for the daily vibration exposure should not be extrapolated to very short durations and large accelerations. Such exposures can be associated with other, acute, injuries to the hand-arm system.

C.2 General health effects

The probability of an individual developing symptoms of the hand-arm vibration syndrome (see annex B) depends on his/her susceptibility, any pre-existing diseases and conditions, and the work-related, environmental and personal factors listed in 4.1 and annex D. The prevalence of symptoms in a group of persons, each of whom performs equivalent work involving a similar tool, or tools, or industrial process in which vibration is coupled to the hands, is additionally dependent on the range of individual and exposure factors in the group. For groups in which persons do not continue the same work, the prevalence of vibration-related symptoms will be also influenced by the rate at which persons leave the group.

NOTE Studies suggest that symptoms of the hand-arm vibration syndrome are rare in persons exposed with an 8-h energy-equivalent vibration total value, $A(8)$, at a surface in contact with the hand, of less than 2 m/s^2 and unreported for $A(8)$ values of less than 1 m/s^2.

C.3 Prevalence of episodic finger blanching (vibration-induced white finger)

There have been attempts to estimate the vibration exposure required to produce different prevalences of finger blanching in groups of persons performing equivalent work involving a similar tool, or tools, or industrial process. Figure C.1 shows the daily vibration exposure, $A(8)$, which is estimated to produce finger blanching in 10 % of exposed persons. Values are shown for group mean total (lifetime) exposures of from 1 year to 10 years. Corresponding values are shown in Table C.1.

Interpolation for exposure conditions between the values shown in Table C.1 is permitted. The following relationship may be used for this purpose:

$$\frac{D_y}{\text{year}} = 31{,}8\left(\frac{A(8)}{\text{m/s}^2}\right)^{-1{,}06} \qquad \text{(C.1)}$$

where

$A(8)$ is the daily vibration exposure (8-h energy-equivalent vibration total value at a surface in contact with the hand);

D_y is the group mean total (lifetime) exposure duration, in years.

NOTE 1 This tentative relationship between vibration exposure and finger blanching is consistent with that given in annex A of the previous version (ISO 5349:1986), and is based on reference [10]. However, correction factors have been applied to take account of the use of the 8-h energy-equivalent vibration total value in this part of ISO 5349.

NOTE 2 The guidance on vascular effects given in this part of ISO 5349 is based on epidemiological studies involving power tools with vibration predominantly above the range 30 Hz to 50 Hz (e.g. chain saws, grinders, rock drills). Therefore, measurements which are dominated by components of frequency-weighted acceleration at lower frequencies, particularly below about 20 Hz, should be treated with caution. Effects on the bones and joints of the upper limbs have been reported in operators of those types of power tool (see annex B).

NOTE 3 The relationship in equation (C.1) does not predict the risk of finger blanching (vibration-induced white finger) occurring in any particular individual within a group.

NOTE 4 Figure C.1 and Table C.1 can be used to define exposure criteria designed to reduce the health hazard of hand-transmitted vibration in a group of occupationally exposed persons. The values in Table C.1 and Figure C.1 are derived from studies of groups of workers exposed to tool vibration magnitudes up to 30 m/s^2 in their occupations for up to 25 years. Almost all studies involved groups of persons who performed, near-daily, work involving one type of power tool or industrial process in which vibration was coupled to the hands. The acceleration values are derived from studies in which the dominant, single-axis, frequency-weighted component acceleration was reported.

NOTE 5 Deviations from the values in Table C.1 and Figure C.1 can occur for tools or processes in which the ratio of the vibration total value to the greatest single axis component deviates significantly from the typical values given in the foreword to this part of ISO 5349. Deviations from the values in Table C.1 and Figure C.1 can also occur for occupational groups in which work-related and/or environmental factors differ significantly from those commonly occurring in similar occupations.

If for a specified total (lifetime) exposure duration, the daily vibration exposure $A(8)$ is in excess of that required to produce a 10 % prevalence of white fingers, a greater prevalence of finger blanching may be expected.

Table C.1 — Values of the daily vibration exposure $A(8)$ which may be expected to produce episodes of finger blanching in 10 % of persons exposed for a given number of years D_y

D_y, years	1	2	4	8
$A(8)$, m/s^2	26	14	7	3,7

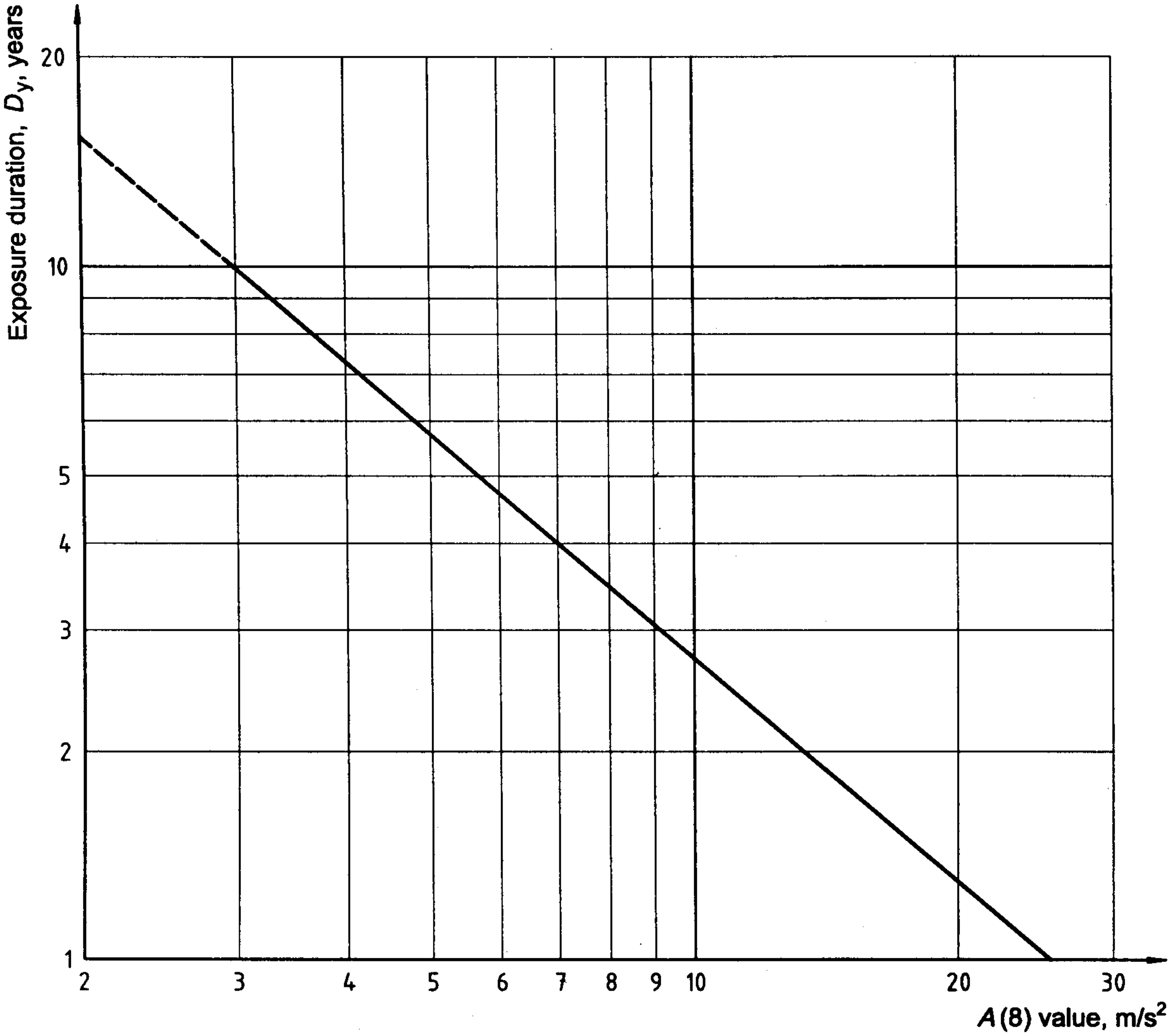

Figure C.1 — Vibration exposure for predicted 10 % prevalence of vibration-induced white finger in a group of exposed persons

Annex D
(informative)

Factors likely to influence the effects of human exposure to hand-transmitted vibration in working conditions

The method for evaluation of vibration exposure described in this part of ISO 5349 takes account of the vibration magnitude, the frequency content, the duration of exposure in a working day and the cumulative exposure to date. The effects of human exposure to hand-transmitted vibration in working conditions may also be influenced by the following:

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

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

c) the individual's age or any predisposing factors in his/her constitution or health;

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

e) the coupling forces, such as the grip and feed forces, applied by the operator through the hands to the tool or the workpiece[2] and the pressure exerted on the skin;

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

g) the type and condition of vibrating machinery, hand-tool and fitted accessory or workpiece;

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

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

i) climatic conditions and other factors affecting the temperature of the hand or body;

j) diseases which affect the circulation;

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

l) noise.

Although the importance of all the factors listed with respect to the generation of vibration disorders is not yet known in sufficient detail, and standardized methods for reporting some factors are not defined in this part of ISO 5349, reporting of all factors is considered desirable in order to enable the collection of meaningful exposure histories (see annex F).

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2) An International Standard on the measurement of gripping and pushing forces is in course of preparation.

Annex E
(informative)

Preventive measures to be adopted by those responsible for occupational health and safety

E.1 Medical preventive measures associated with regular exposure to hand-transmitted vibration

The following steps should be taken.

a) Any worker who may have to expose his hands to vibration should, prior to employment,

— be physically examined, and

— have any previous history of vibration exposure recorded.

b) All individuals who use vibrating equipment should be advised of the risk of exposure to hand-transmitted vibration.

c) Persons with the following medical conditions might be at greater risk and should be carefully assessed before they use vibrating equipment:

— primary Raynaud's disease;

— disease caused by impairment of blood circulation to the hands;

— past injuries to the hand causing circulatory defects or deformity of bones and joints;

— other causes of secondary Raynaud's phenomenon;

— disorders of the peripheral nervous system;

— disorders of the musculoskeletal system.

d) Provision should be made for the reporting of symptoms and arrangements made for medical check-ups, at regular intervals, of those at risk.

In some countries it is recommended that young people (under 18 years) do not use certain vibrating tools.

NOTE A glossary of medical terms can be found in clause B.6.

E.2 Technical preventive measures aimed at reducing the effects of vibration exposure of the hands

The following steps should be taken.

a) Where there is a choice between different processes, the process resulting in the lowest vibration exposure should be used.

b) Where there is a choice between different tools, the tool (with accessories) resulting in the lowest vibration exposure should be used.

c) Equipment should be carefully maintained in accordance with the manufacturer's instructions.

d) Tools should be prevented from expelling cold gases or fluids over the operator's hands.

e) If possible, the handles of the vibrating equipment should be heated when working in cold conditions.

f) Tools with handle shapes which result in high pressures on the skin in the area of contact should be avoided.

g) Tools requiring the smallest contact forces (grip and feed forces) should be selected where there is a choice.

h) The mass of hand-held tools should be kept to a minimum, provided other parameters, such as vibration magnitude or contact forces, are not increased.

Anti-vibration gloves, as defined in ISO 10819, can be beneficial where they can be shown to reduce the vibration exposure as defined in this part of ISO 5349. (However, anti-vibration gloves should not be expected to provide a sufficient means of protection from hand-transmitted vibration.)

E.3 Administrative preventive measures aimed at reducing the effects of vibration exposure of the hands

The following steps should be taken.

a) There should be adequate training to instruct the worker in the proper use of the equipment.

b) It is presumed that vibration hazards are reduced when continuous vibration exposures over long periods are avoided; therefore, work schedules should be arranged to include vibration-free periods.

c) There should be provision for workers to keep warm.

E.4 Advice to individuals who use vibrating hand tools

The following advice is given.

a) Let the tool do the work and grip the tool as lightly as possible, providing that this is consistent with safe work practice and tool control. The tool should rest on the workpiece or support as much as possible.

NOTE In some situations, increasing the feed and grip forces can decrease the measured acceleration although this may not be beneficial.

b) Inform the appropriate work supervisor if abnormal vibration occurs.

c) Wear adequate clothing and suitable gloves to keep dry and warm, particularly when working, travelling or using vibrating equipment.

d) Avoid or minimize smoking tobacco or using snuff before and during work with vibrating equipment, since nicotine reduces the blood supply to the hands and fingers.

e) Seek medical advice if attacks of white or blue fingers occur or long periods of finger tingling and/or numbness are experienced.

E.5 Further information

Further advice is available in CR 1030-1 and CR 1030-2.

Annex F
(informative)

Guidelines for reporting additional information

F.1 Introduction

The principal quantities currently used to represent the severity of exposures to hand-transmitted vibration are a_{hv} and $A(8)$ as defined in this part of ISO 5349. However, the characteristics of vibration that cause health disorders are not fully understood; it is possible that, as understanding increases, there will be a need to amend some aspects of the evaluation method, such as the frequency weighting, frequency range, time-dependency and the approach to multi-axis vibration. It may also be necessary to specify different analysis methods for different effects of human exposure to hand-transmitted vibration.

In order to maximize the future value of vibration measurements made using this part of ISO 5349, and to further the knowledge of the effects of hand-transmitted vibration, it is recommended that additional information be reported when measurements and assessments of exposure to vibration are made. This annex gives guidelines for the reporting of useful additional data.

F.2 Vibration source and tool operation

A clear description of the vibrating tool, its type, age, mass, size and condition should be given. The vibration characteristics of a vibrating tool can be highly variable. It is therefore important that the range of vibration conditions associated with different workpieces and materials, working conditions, methods of use of the tool and exposure duration patterns (including intermittency) reported.

The positions and orientations of the operator's hands on the vibrating tool or workpiece surface should be reported. The operator's posture should be described, particularly with regard to the hands and arms.

The contact forces between the hand and the gripping zone are likely to affect the vibration energy transferred to the hand, although the effects are not fully understood. It is possible that future vibration standards will require these forces to be determined. Where possible, the contact forces should be measured or estimated.[3)]

Environmental factors, such as noise, temperature, chemical agents at the workplace, etc., should be reported where possible.

F.3 Instrumentation

This part of ISO 5349 requires that the measurement or recording system shall conform to the requirements of ISO 8041. Where the requirements of this part of ISO 5349 are exceeded (e.g. if the frequency range is greater) a full description of the instrumentation should be given.

The position and orientation of the transducers on the tool or workpiece and the method of mounting should be fully described. The total mass of the transducer(s) and mounting device should be quoted.

The method of mounting the accelerometer can make a major contribution to the frequency response of the instrumentation. It is important to ensure that any resonance frequencies are high enough above the upper limit of the measurement frequency range.

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3) An International Standard on the measurement of gripping and pushing forces is in course of preparation.

F.4 Axes of vibration

This part of ISO 5349 requires that vibration is measured and reported separately for the three axes x, y and z. It is desirable that data for all three axes of measurement (including frequency-weighted r.m.s. magnitudes, frequency spectra and time histories where available) should be reported.

NOTE Reporting of data for all axes is advisable for the following reasons:

a) some currently recommended evaluation methods are based on the vibration total value, while others use the greatest measured single-axis value;

b) the effects of vibration direction on health are not yet fully understood.

F.5 Vibration time histories

Acceleration time histories should be recorded and retained, if possible. Recorded vibration time histories are of limited use unless their frequency band limits and the characteristics of the band-limiting filters are reported.

NOTE The preservation of the time history is desirable for the following reasons:

a) it enables measurement artifacts to be identified (e.g. d.c. shifts, overloads);

b) different methods of frequency analysis may be used on the same data;

c) root-mean-square averaging, as required by this part of ISO 5349, may not be the most appropriate method of evaluation; alternatives (e.g. peak acceleration, root-mean-quad average) may be determined from a stored vibration time history;

d) a different form of analysis may be appropriate for impulsive vibration (e.g. with percussive tools); peak or crest factor analysis, for example, may be useful; such alternative analysis methods have not yet been agreed.

F.6 Frequency analysis

In addition to frequency-weighted magnitudes, it is desirable to report (unweighted) one-third-octave band root-mean-square acceleration magnitudes over the frequency range of the measurement system.

In addition, constant-bandwidth spectra (e.g. power spectral densities) can provide a useful visual method for inspecting data for frequency content and for the detection of measurement artifact. (It is important that the frequency resolution be quoted where power spectra are reported.)

NOTE Frequency analysis is desirable for the following reasons:

a) subsequent re-analysis using one-third-octave band data and an alternative frequency weighting is simple. (This is particularly useful if vibration time histories are not preserved.)

b) spectral information (particularly from a constant bandwidth analysis) can be useful for detection of artifacts: overloads or d.c. shifts (evident at low frequencies) and transducer mounting problems (evident at high frequencies);

c) narrow-band frequency analysis can assist in identifying the mechanisms causing the vibration and can thus provide engineers with the means to reduce vibration at problem frequencies.

F.7 Frequency range

Although the frequency weighting W_h is defined only within a specified frequency range, it is recommended that the measurement frequency range should be as great as is practicable if time histories and/or frequency analyses are to be reported. However, transducer mounting response at frequencies above approximately 1 000 Hz can cause difficulties; the validity of any high-frequency data should, therefore, be justified.

NOTE Reporting of data with a greater frequency range is desirable because some researchers believe that frequencies above 1 250 Hz may be more important than this part of ISO 5349 suggests, particularly for impulsive vibration.

F.8 Epidemiological information

Understanding of the effects of vibration on health (including effects on the vascular, neurological and musculo-skeletal systems) will be improved by the continued reporting of studies in which **both** vibration exposure (derived in accordance with this part of ISO 5349, and taking account of the content of this annex) **and** the resulting health effects are recorded.

Guidance on the reporting of epidemiological data is beyond the scope of this annex.

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