GUIDELINES ON OCCUPATIONAL VIBRATION

Department of Occupational Safety and Health
Ministry of Human Resources
Malaysia

JKKP : GP (1) 1/2003
ISBN : 983-2014-24-7

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Preface

This guideline deals with vibration as this physical phenomena may effect the human body, and has a detrimental effect relating to occupational safety and health.

The effects of direct vibration on the human body can be serious. Vibration can typically cause blurred vision, loss of balance, loss of concentration etc. In some cases, certain frequencies and levels of vibration can permanently damage internal body organs. In this respect "white fingers syndrome" is a particular concern.

This guideline is intended to increase the awareness of employers as well as employees to the effect of vibration to the human body, and provide guidance on how to avoid or prevent the risk of vibration related discomfort and damage to the human body.

The guideline shall be deemed to be a document in addition to and not in derogation of any written law.

In accordance with Section 15(1) and 15(2)(a) & (b) of the Occupational Safety and Health Act 1994 (Act 514) with state, respectively, that:
"It shall be the duty of every employer and every self-employed person to ensure, so far as practicable, the safety, health and welfare of all his employeers"; and
"without prejudice to the generality of subsection (1), the matters to which the duty extends include in particular;
(a) the provision and maintenance of plant and system of work that are, so far as practicable, safe and without risks to health;
(b) the making of arrangements for ensuring, so far as is practicable, safety and absense of risks to health in connection with the use or operation, handling, storage and transport of plant and substances."

Director General
Department of Occupational Safety and Health
Malaysia

Julai 2003

1.0 INTRODUCTION

Human vibration is normally defined as the vibration experienced by the human body as a result of direct contact with vibrating surfaces. These surfaces include the floor of buildings, the seats of vehicles and the handles of power-driven tools.

Vibration may cause discomfort, a reduction in work output or even physical damage. In order to quantify and assess safe levels of human exposure to vibration, measurements and analysis of vibrations are therefore necessary.

Human vibration can be categorised by response into two major areas of evaluation; i.e. whole-body and hand-arm.

1.1 DEFINITIONS

1.1.1 Vibration

Vibration is typically an oscillatory motion of a mechanical system or body. The magnitude of vibration can be described by the displacement (mm) of this motion above some reference point or alternatively by the rate of change of this displacement [ie. velocity (m/s) or acceleration (m/s^2)] with reference to time.

1.1.2 Vibration, Hand-transmitted

Excersive vibration can be transmitted from vibrating tools, vibrating machinery or vibrating workplace to the hand and arms of operators. These situations occur, for example, in the manufacturing, mining and construction industry when handling pneumatic and electrical tools, and in forestry work when handling chain saws. These vibrations are transmitted through the hand-arm to the shoulder. Depending on the work situation, these vibration can be transmitted to the arms simultaneously. Hand-transmitted vibrations generally occur in the frequency range of 8 - 100Hz.

1.1.3 Vibration, Whole-body

Vibration transmitted to the body as a whole through the supporting surface, namely the feet of a standing man, the buttocks of a seated man or the supporting area of a reclining man. Such form of vibration transmission are common in vehicles, vibrating building structures and working in the vicinity machinery. In principle, it applies to vibration transmitted from solid surfaces to the human body in the frequency range of 1 - 80Hz. Vibration in the frequency range below 1Hz creates special problem, associated with symptoms such as kinetosis (motion sickness), which are of a character different from the effects of higher frequency vibrations. The inception of such symptoms depends on complicated individual factors not simply related to the intensity, frequency or duration of the provocative action.

1.1.4 Frequency of Vibration

Frequency of vibration is the number of times a complete motion cycle (oscillating motion) take place during the period of a second, and is measured in cycles per second termed hertz (Hz).

1.1.5 'X'- axis

This is a orthogonal axis in the forward facing direction of a standing person.

1.1.6 'Y'- axis

This is a orthogonal axis in the transverse direction (at right angle to the 'x' axis) of a standing person.

1.1.7 'Z'- axis

This is a orthogonal axis in the vertical direction of a standing person.

2.0 VIBRATION MEASUREMENT

2.1 General

2.1.1 Vibration measurement shall be undertake to quantify the level of vibration to which workers are exposed.

2.1.2 The measurement of vibration in general shall normally be taken on a structural surface supporting a human body or on some surface other than the point of entry to the human subject.

2.1.3 The method of measuring the whole-body and hand-arm vibration is prescribed in Appendix A.

2.1.4 (1) Vibration shall be measured as close as possible to the point or area through which it is transmitted to the body.

(2) If such transmission has to pass through a cushion or depends on others factors, the vibration attenuation of these factors shall be taken into account in the vibration measurement.

2.2 Measuring Equipment

2.2.1 (1) Vibration measuring equipment shall typically consist of the following: a transducer or pick-up sensor, an amplifying device (electrical, mechanical or optical), an amplitude or level indicator or recorder, and a signal analyser.

(2) Where appropriate, networks or filter may be included to limit the frequency range of the equipment, and to apply the recommended frequency-weighting to the input signal. An rms-rectifying device may also be included for convenience such that rms values may be read off and quantified directly.

2.2.2 The measuring and analysing equipment used shall comply with the relevant International and National Standards. Vibration transducer for example shall be in compliance to International Electrotechnical Commission (IEC) Publication 184, and auxiliary equipment (amplifiers, frequency selective equipment and carrier systems) in compliance to IEC Publication 222.

2.2.3 Vibration frequency analysers or signal analysers (of either type based on instrumentation hardware, or computer software digital signal processor) with one third octave filter sets or narrow band FFT (fast fourier transform) bandwidth, shall be used for vibration frequency analysis in the frequency range 1 to 100 Hz minimum.

2.2.4 Measuring and analysing equipment shall be used in accordance with the manufactures instructions.

2.3 Instrument Accuracy and Calibration.

2.3.1 All vibration measuring equipment shall be properly calibrated in accordance with existing standards or recommendation and/or manufactures instructions governing the calibration of such equipment.

2.3.2 Measuring and analysing equipment shall be tested at suitable intervals. A qualified personnel responsible for the upkeep of the measure instruments shall draw up a calibration and testing schedule to be kept with the instrument.

2.3.3 The person responsible for maintenance and testing of measuring and analysing equipments shall be specially trained, and shall be responsible for ensuring that the equipment is kept in good condition.

2.4 Recording of Data

2.4.1 When vibration is measured at places of work, comprehensive data shall be collected, in particular regarding:-

a) the characteristics of the source of vibration investigated, and the type of work being performed;

b) the characteristics of the path or manner in which vibration is transmitted to human body (Hand-arm or Whole-body vibration);

c) the point at which (including the description of any intermediary elements such as sheets) and the pick-up device with which measurement were made, and the values obtained;

d) the measurement instrumantations used, its accessories and their characteristics (including sensitivity, dynamic properties and fineness of resolution);

e) the numbers of workers exposed to vibration;

f) the duration of worker's exposure; and

g) the date and time, and the name of the observer.

2.4.2 The data collected shall be suitably recorded. It is recommended that specific test record form shall used for this purpose.

3.0 VIBRATION LIMITS

3.1 General

3.1.1 (1) Recommended vibration limits as stipulated herein this guide-line shall be used with the intention for protecting the safety and health of workers relating to:

a) vibration affecting the hands and arms (vibration tools); and

b) whole-body vibration transmitted through the supporting surface.

(2) Vibration limits shall be laid down depending on the work to be done, and to avoid human fatique.

3.1.2 The limits shall be reviewed from time to time in the light of new scientific knowledge, technical progress and possibilities of prevention.

3.2 Vibration Transmitted to Hand-arm

3.2.1 (1) Vibration levels encountered in many commonly used power tools are sufficiently high to be a health hazard to humans when operated for typical work durations in the industry.

(2) Common powers tools include chipping hammers, powers grinders, hammer drills, and chain saws found in widespread use in the mining, construction, manufacturing and forestry industries.

3.2.2 Vibration may be transmitted into the body from a vibrating tool or hand-held workpiece via one or both arms simultaneously. At lower vibrations levels, consequential effects are typically discomfort and reduced working efficiency.

3.2.3 (1) At higher vibration levels and longer exposure periods, diseases affecting the blood vessel, joint and circulation are often resulted.

(2) Severe exposure typically leads to a progressive circulation disorder in the part of the body suffering the highest level of vibration, usually the fingers or hand where hand-held tools are concerned. This disorder is know as Raynaud's disease, or commonly referred to as 'dead hand', vibration -induced white finger or Raynaud's disease.

(3) In extreme cases the above disorder leads to permanent damage or gangrene.

3.2.4 (1) The recommended "Threshold Limit Values" defining vibration acceleration component levels and duration of exposure for hand-arm vibration are prescribed in the Appendix B.

(2) These values shall be used as a basis for the control of hand-arm vibration exposure. Because of individual susceptibility, these values however should not be regarded as defining a boundary between safe and dangerous levels.

3.3 Whole-body Vibration

3.3.1 (1) Vibration levels encountered in whole-body motion is transmitted to the body as a whole, usually through the supporting surface (feet, buttocks, back, etc.).

(2) A person driving a vehicle, for example, is subjected to whole-body vibration through the buttocks, and if there is back support through the back as well.

3.3.2 Exposure to whole-body vibration can either cause permanent physical damage, or disturb the nervous system.

3.3.3 (1) Daily exposure to these vibration over a period of time (typically a number of years) can result in serious physical damage, for example, ischemic lumbago. This is a condition affecting the lower spinal region, and can also affect the exposed person's circulatory and/or urological system.

(2) People suffering from the effect of long-term exposure to whole-body vibration would have usually been exposed to this damaging vibration related to some particular task at work.

3.3.4 (1) Over exposure can also disturb the central nervous system. Symptoms of this disturbance usually appear during, or shortly after exposure in the form of fatigue, insomnia, headache and "shakiness".

(2) Many people have experienced these nervous symptoms after they have completed a long car trip or boat trip. The symptoms however usually disappear after a period of rest.

3.3.5 The recommended "Threshold Limit Values" which refer to component acceleration levels and duration of exposure for whole body vibration are prescribed in the Appendix C.

3.3.6 (1) The vibration levels indicated by the curves in figures - and - (Appendix C) are given in terms of RMS acceleration level which indicates equal fatique - decreased proficiency.

(2) Exceeding the exposure specified by the curves will, in most situations cause noticeable fatique and decreased job proficiency in most tasks.

(3) The degree of task interference depends on the subject and the complexity of the task. These curves however indicate the general range for onset of such interference and the time dependency observed.

3.3.7 (1) The criteria are presented as recommended guidelines or trend curves and are not intended to be firm boundaries classifying quantitative biological or phycological limits.

(2) The above defined criteria are intended only for situations involving health for normal people considered fit for normal living routines and the stress of an average working day.

4.0 IDENTIFICATION OF RISKS AREAS

4.1 Risk Assessment

4.1.1 Vibration, shall be measured in all places of work where:-

a) the work done or the working environment possibly will involve a risk due to vibration;
b) Occupational Safety and Health audit or inspection disclosure that such risks may exist; and
c) the workers maintain that they are subjected to an uncomfortable or disturbing level of vibration.

4.2 Source of Vibration

4.2.1 The sources of vibration shall be identified by suitable measurements and investigation.

4.2.2 If the vibration level vary widely because of a change in working condition (as when machine-tool runs unload and the start working), account shall be taken for the least favorable condition. It is nevertheless suggested that separate series of measurements be undertaken.

4.3 Assessment of Exposure

4.3.1 Measurements shall be made at locations normally occupied by the workers in the area under observation.

4.3.2 Measurements shall be made of the vibration transmitted to the whole-body and of the vibration transmitted to a particular part of the body.

4.4 Marking of Areas and Equipment

4.4.1 Equipment (fixed or portable), which may cause vibration in excess of the maximum vibration limits under section 5.0 shall be clearly marked with an indication of the risk, the maximum period of use, and the personal protective equipment needed.

5.0 VIBRATIONS PREVENTION AND CONTROL

5.1 Aims

5.1.1 The aim of vibration prevention programmes is to eliminate safety and health risks arising from the effect of vibration, or to reduce these vibration to the lowest feasible levels by all appropriate means.

5.1.2 The vibration to which workers are exposed, and the time during which they are exposed, shall not exceed the recommended threshold limits as stipulated in this document. (See section on vibration limits)

5.2 Control

5.2.1 All appropriate measures shall be taken at the source to prevent vibration generation, transmission, and amplification of vibration when machinery and equipment is designed or selected. Vibration emissions shall be a factor to be taken into account when machinery and equipment is to be procured.

5.2.2 (1) Attempts shall be made to ascertain at which locations, if any, vibration will exceed the recommended threshold limits.

(2) There locations shall be identified, marked out, and suitably indicated.

5.2.3 Engineering measures shall be taken to control vibration with a view to reducing vibration level below the recommended limits.

5.2.4 When the above prove impossible, provisions shall be made by a reorganisation of work, the use of personal protective equipment or any other suitable means to reduce the exposure below the recommended safe exposure limits.

5.2.5 The health of workers likely to be exposed to vibration, at levels exceeding the recommended threshold limits, including the workers whose exposure is limited by personal protective equipment or by adminstrative arrangements which reduce exposure time, shall be strictly supervised.

5.2.6 The monitoring of the working environment, shall be systematic and repeated as often as necessary to ensure that vibration risks are kept under control. The monitoring shall be carried out by a competent person.

5.3 Implementation

5.3.1 Every organisation shall implement a general prevention programme that take due consideration to its own specific features. In this respect the employer should define and assign responsibilities in the prevention programme.

5.3.2 The organisation may assign the Safety and Health Officer or other qualified persons responsibilities and duties in connection with vibration prevention to include, but not limited to:

a) the design of new plants and equipment, or studies of new processes;

b) the purchase of machinery or equipment;

c) contracts entered into with contractors;

d) the information and training given to workers; and

e) the purchase of personal protective equipment, and the provision of instruction in regard to its use.

5.3.3 Vibration control shall preferably be achieved by collective measures with the assistance of the qualified persons. Improvement that are recommended shall be made forthwith by the Employer.

5.3.4 The personnel, who is responsible for vibration measurements in the working environment shall:

a) have received appropriate training in the measurement and control of vibration; and

b) be equipped with suitable measurement instruments.0

5.3.5 The medical surveillance of the workers shall be carried out -

a) under the responsibility of a registered medical practitioner competent to interpret the results of the special tests which are made; and

b) with the assistance of qualified supporting staff that has received appropriate training concerning the special tests to made and the use of personal protective equipment.

5.4 Vibration Control for New Equipment

5.4.1 Manufacturers shall so design the equipment they produce (embodying therein suitable control measure) such that the vibration emitted is at the lowest feasible level.

5.4.2 (1) Manufactures shall provide information concerning the availability of accessories that are not provided with the equipment itself, but that may be useful or essential in the control of vibration.

(2) Manufactures shall also provide information concerning the installation of such accessories so as to obtain maximum efficiency and work safety benefits.

5.4.3 Manufactures shall provide full information about levels of vibration emitted, as well as on means of controlling them.

5.4.4 When ordering equipment, the purchaser shall specify maximum limits for the vibration emitted.

5.4.5 Testing for new equipment to assess vibration shall be performed, and the levels of vibration shall be below the safe vibration threshold limits.

5.5 Replacement of Hazardous Equipment or Processes

5.5.1 Whenever possible, processes and equipment producing less vibration shall be given preference.

5.5.2 It shall be preferable to purchase equipment that is quieter or produce less vibration at the initial onset, as compared to undertaking remedial measure in addressing excessive vibration.

5.6 Design and Installation

5.6.1 Vibration control shall begin with the design and planning of new plants, installations and processes. Control measure shall be based on relevant information, and in particular-

a) a knowledge of the vibration characteristics of the equipment and processes to be used;

b) the choice of suitable construction; and

c) the isolation of operations or plant giving rise to high vibration that is difficult to control.

5.6.2 As far as possible, preference shall be given to materials and structures having a high isolating factor or attenuation factor, or combination of both.

5.6.3 Once a suitable equipment has been chosen, its installation shall be studied with due regard to -

a) the kind of vibration likely to be emitted;

b) the number and type of machines and other equipment; and

c) the number of workers employed on the particular work premises.

5.6.4 Measurement shall be made as soon as the machine and equipment are installed, in order to establish the resulting vibration levels.

5.7 Vibration Control in the Working Environment

5.7.1 In the work premise, the strategy of controlling vibration as explained in paragraph 7.4 to 7.6 shall be made used as the first level of control strategy. In order to further reduce the vibration level, or if the initial strategy did not sufficiently reduce the vibration to levels below the limits stipulated herein this document, actions proposed hereafter can be taken.

5.7.2 (1) Vibration control at the work place can be categorised as follows -

a) reducing vibration produced and emitted by the source;

b) preventing the propagation, and amplification of vibration; and

c) isolating the workers.

(2) Vibration shall also be attenuated, as appropriate in particular cases, ensuring safe distances of workers from the vibration source; or by isolating the workers exposed to the vibration, either by collective measures or by personal protective equipment.

(3) The various control methods may be combined in order to achieve a suitable reduction in vibration levels.

5.7.3 The control of vibration at source shall be drawn between the following three main types of vibration according to their source-

a) Vibration attributable to the vibration of a solid or liquid (mechanical forces);

b) Vibration attributable to turbulence occurring in a gaseous medium (aerodynamic forces); and

c) Vibration attributable to electrodynamic or magnetodynamic forces, or to electrical arc or corona discharge (electrical forces).

5.7.4 Good work practices shall be used and shall include instructing workers to employ a minimum hand grip force consistent with safe operation of the power tool or processes, to keep their body and hands warm and dry, and to use anti-vibration tools and gloves which are effective for damping vibration at high frequencies.

5.7.5 Methods of controlling sources of vibration shall include but not limited to:

a) reducing the intensity of vibration by dynamic balancing of machinery components, reducing the driving force acting on vibrating part, reducing machinery speed, and rectifying any mechanical faults (misaligement, etc);

b) reducing the vibration emission efficiency of the vibrating parts by increasing their damping capacity, and improving manner machinery components are attached;

c) reducing turbulence and the rate of flow of fluids at inlets, in ducts or pipes, and at outlet;

d) changing from impact action to progressive pressure action;

e) changing from reciprocating movement to rotating movement;

f) changing from sudden stopping to progressive braking;

g) changing from cylindrical toothed gears to helical gears, and from metal gears to gears of others materials where feasible;

h) design of the shape and speed of tools with due regard to the characteristic of the material worked;

i) design of adequate system for fixing the materials or objects to be worked;

j) prevention of the striking of objects or materials being transported mechanically, and prevention of their free fall from conveying equipment;

k) design of burners, torches and combustion and explosion chambers with appropriate characteristics;

l) adequate design of electrical machinery in regard to electrodynamic, magnetodynamic and aerodynamic forces;

m) insertion of adequate damping joints at connecting point of machinery and equipment;

n) adequate design of fan blades;

o) adequate design of air tubing and ducting system (compressed air, ventilation air), and gas or liquid tubing system to prevent the propagation of vibration and resonance excitation; and

p) the use of vibration isolation device or systems (such as spring vibration isolators, elastomeric pads, visco-damping systems), and flexible connections within the equipment.

5.7.6 The maintenance of equipment shall receive special attention so as to prevent any abnormal increase in vibration emitted by the source.

5.7.7 Maintenance personnel shall be adequately trained in lubrication, replacement of worn-out parts, and the regular and correct adjustment maintenance of machinery as well as anti-vibration devices.

5.7.8 The control of propagation, and amplification of vibration shall include:

a) the mounting of machinery on foundations vibration isolated from the floors, walls and other supporting structures;

b) the use of mechanical vibration isolators (typyically steel spring, elastaneric or pneumatic isolating elements) for the mounting machinery, pipeworks, and etc;

c) the use of resilient materials between building elements (control rooms, floor-joints, and etc);

d) the siting of vibrating machinery so that it does not come into contact with other parts of the installation and the workrooms; and

e) ensuring that rotating or reciprocating machinery does not operate at speeds in close proximity to structural resonant frequencies.

5.7.9 The anti-vibration qualities of the material used for the construction of premises, equipment and enclosures should be carefully considered.

5.8. Protective Equipment and Reduction of Exposure Time

5.8.1 In cases when vibration levels cannot be brought below the danger limit either by suitable installation, the following measures shall be taken:-

a) the workers shall be provided with anti-vibration working platforms or stands;

b) the workers shall be provided with anti-vibration devices; or

c) the duration of exposure shall be limited.

5.8.2 Personal protective equipment and limitation of exposure time should bring workers' exposure within permissible limits.

5.8.3 (1) Anti-vibration equipment shall on no account be regarded as adequate substitutes for prevention.

(2) The above stipulated measure are to be regarded as interim measure keep risks within acceptable limits, until such time as vibration control can be made more effective through engineering mesures.

5.8.3 Every effort shall be made to ensure that workers use the personal protective equipment provided.

5.8.4 When vibration levels cannot be brought within permissible limits, the duration in which the workers are exposed to the vibration must be reduced.

5.8.5 The following option shall be considered with a view to reducing the duration of vibration exposure -

a) rotation of jobs;

b) reorganisation of job function such that part of the work can be done without exposure to the risks; and

c) provision of breaks.

9.0 REFERENCES

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APPENDICES

APPENDIX A

VIBRATION MEASUREMENT

1) General

It is essential that human-vibration is accurately measured such that an assessment can be made on:

a) the discomfort produced by the vibration; and

b) the possible danger involved in being exposed to the vibration, and the necessary steps can be taken to reduce these factors.

The accuracy of human-vibration measurement depends on the quality of the measurement instrumentation, the analysis and recording of data. The transducer which is now almost universally used for wholebody and handarm vibration measurements is the piezoelectric accelerometer.

Is extremely important when measuring human vibration that the vibration is measured as close as possible to the point or area through which the vibration is transmitted to the body.

2) Whole-body vibration

For whole-body vibration, vibration enter the body at the floor/foot, seat/back or seat/buttocks interface, and vibration measurements shall therefore be measured at these point. An example of a transducer for measuring whole-body vibration is a seat transducer which is a triaxial seat accelerometer. This transducer can be positioned at the excitation point without disturbing the original position of the workers. The transducer shall have three independent accelerometers which simultaneously measure the vibration level in three orthogonal axes (x,y and z).

3) Hand-arm vibration

When a vibrating object is held in the hand vibration transmit to the hand and arm through the palm of the head. The transducers shall therefor be mounted at a location on the surface of contact between the palm of the hand and the vibrating object. The measurement exercise shall not interfere with the work process, or of the hand on the vibrating object.

When hand-arm vibrations are measured in work situations, care shall be taken to protect the cable connecting the accelerometer to the measurement-recording equipment.

4) Vibration measurement system

A typical human-vibration measurement system is illustrated in the diagram bellow:-

TRANSDUCER (accelerometers)	Pick-up vibration signal
↓	
AMPLIFYING DEVICES	Vibration signal are weighted to allow of human response to vibrations of different frequencies.
↓	
AMPLITUDE, or LEVEL INDICATOR, or RECORDER	Acceleration in RMS values
↓	
SIGNAL ANALYSER	Analysis of the vibration signal to the various parameters to obtain: - Instantaneous and equivalent RMS values - Instantaneous and maximum peak values - Maximum and minimum RMS values - Equivalent acceleration value - Frequency spectrum of the vibration (vibration frequency components).

APPENDIX B

Threshold Limit Values (TLV) for Vibration Transmitted to Hand-arm

1) The TLVs in Table 1 refer to component acceleration levels and durations of exposure that represent conditions under which it is believed that nearly all workers may be exposed repeatedly without progressing beyond stage 1 of Table 2. These values shall be used as guides in the control of hand-arm vibration exposure. Because of individual susceptibility the levels shall not be regarded as defining a boundary between safe and dangerous levels.

TABLE 1 Thereshold Limit Values for Exposure of the Hand to Vibration in Either X_h, Y_h, Z_h.

Total Daily Exposure Duration#	Values of the Dominant,* Frequency - weighted, rms, Component Acceleration Which Shall not be Exceeded a_K, (a_{Keq})	
	m/s^2	g^
4 hours and less than 8	4	0.40
2 hours and less than 4	6	0.61
1 hours and less than 2	8	0.81
less than 1 hour	12	1.22

\# The total time vibration enters the hand per day, whether continuously or intermittently.

* Usually one axis of vibration is dominant over the remaining two axes. If one or more vibration axes exceeds the Total Daily Exposure then the TLV has been exceeded.

^ $g = 9.81 m/s^2$

TABLE 2 : Stockholm Workshop HAVS Classification System for Cold-induced Peripheral Vascular and Sensorineural Symptoms

		Vascular Assessment
Stage	Grade	Description
0	-	No attacks
1	Mild	Occasional attacks affecting only the tips of one or more fingers.
2	Moderate	Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers.
3	Sereve	Freguent attacks affecting ALL phalanges of most fingers.
4	Very Severe	As in stage 3, with trophic skin changes in the finger tips.

Note : Separate staging is made for each hand, e.g. 2L(2) /1R(1)= stage 2 on left hand in 2 fingers : stage 1 on right hand in 1 fingers.

	Sensorineural Assessment
Stage	Symptoms
0SN	Exposed to vibration but with no symptoms
1SN	Intermittent numbness, with or without tingling
2SN	Intermittent or persistent numbness, reducing sensory perception
3SN	Intermittent or persistent numbness, reducing tactile discrimination and or manipulative dexterity.

Note: Separate staging is made for each hand.

2) The vibration acceleration of a vibrating handle or work piece shall be determined in three mutually orthogonal directions at a point close to where vibration enters the hand. The directions shall preferably be those forming the biodynamic coordinate system but may be a closely related basicentric systems with its origin at the interface between the hand and the vibrating surface (figure 1) to accommodate different handle or work place configurations. A small and lightweight transducer-handle shall be mounted so as to record accurately one or more orthogonal component of the source vibration in the frequency range from 5 to 1500Hz. Each component shall be frequency-weighted by a filter network with gain characteristics specified for human-response vibration measuring instrumentation, to account for the change in vibration hazard with frequency (figure 2).

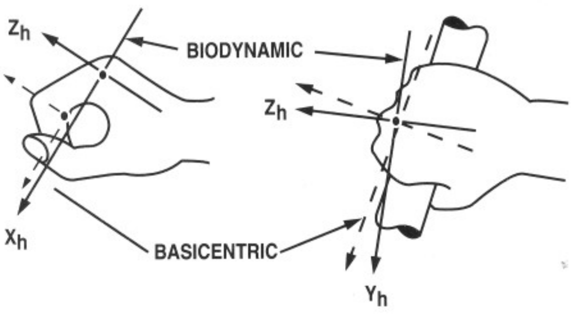

FIGURE 1 :Biodynamic and basicentric coordinate systems for the hand, showing the direction of acceleration components. Adapted from ISO 5349.

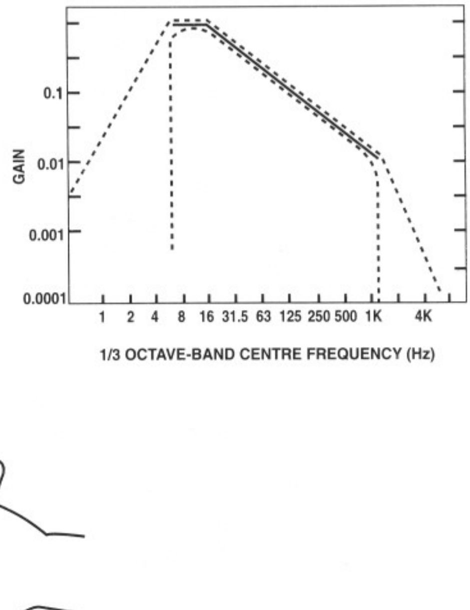

FIGURE 2 :Gain characteristics on the filter network used to frequency-weight acceleration components (continuous line). The filter tolerances (dashed lines). Adapted from ISO 5349.

3) Assessment of vibration exposure shall be made for EACH applicable direction (X_h, Y_h, Z_h) since vibration is a vector quantity (magnitude and direction). In each direction, the magnitude of the vibration during normal operation of the power tool, machine or work piece shall be expressed by the root-mean-square (rms) value of the frequency-weighted component accelerations, in units of meters per second squared (m/s^2), or gravitational units (g), the largest of which, a_K forms the basis for exposure assessment.

4) For each direction being measured, linear integration shall be used for vibrations that are of extremely short duration or vary substantially in time. If the total daily vibration exposure in a given direction consists of several exposures at different rms accelerations, then the equivalent, frequency-weighted component acceleration in that direction shall be determined in accordance with the following equation:

$$\left(a_{Keq}\right) = \left[\frac{1}{T}\sum_{i=1}^{n}\left(a_{K_i}\right)^2 T_i\right]^{1/2}$$

$$= \sqrt{\left(a_{K_1}\right)^2 \frac{T_1}{T} + \left(a_{K_2}\right)^2 \frac{T_2}{T} + \ldots \left(a_{K_n}\right)^2 \frac{T_n}{T}}$$

Where $T = \sum_{i=1}^{n} T_i$

T = total daily exposure

a_{K_i} = *ith* frequency - weighted, rms acceleration component with duration T_i

Ex. If the frequency-weighted acceleration for exposure time of 1,3 and 5 hour

are respectively 15, 12 and 10 $m.s^{-2}$ than;

$$a_{Keq} = \left[\frac{(15^2 \times 1) + (12^2 \times 3) + (10^2 \times 5)}{9}\right]$$

$$a_{Keq} = 11.3\ m.s^{-2}$$

These computations are often in-built within the functions of commercially available human-response vibration measuring instruments.

APPENDIX C

THRESHOLD LIMIT VALUES (TLV) FOR VIBRATION TRANSMITTED TO WHOLE-BODY

1) The TLVs in figure 3 and 4 (tabulated in table 3 and 4) refer to mechanically-induced whole-body vibration (WBV) acceleration component root-mean-square (rms) magnitudes and duration under which it is believed that workers may be exposed repeatedly with minimum risk of back pain, adverse health effect to the back, and inability to operate a land-based vehicle properly. The biodynamic coordinate system to which they apply is shown in figure 5. These values shall be used as guides in the control of whole-body vibration exposure. Because of individual susceptibility, these limits shall not be regarded as defining a boundary between safe and dangerous.

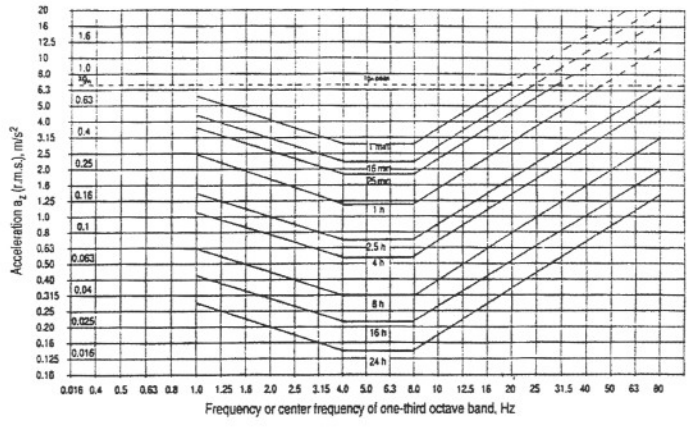

FIGURE 3 :Longitudinal (a_z) acceleration limits as a functional of frequency and exposure time. Adapted from ISO 2631

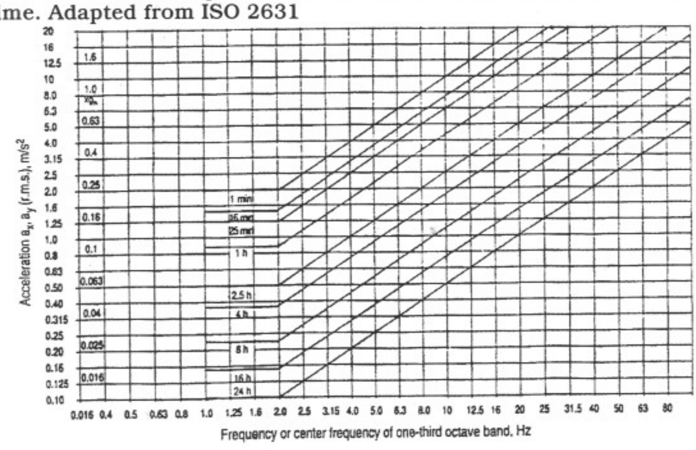

FIGURE 4 :Transverse ($a_x a_z$) acceleration limits as a functional of frequency and exposure time. Adapted from ISO 2631

TABLE 3: Numerical values for vibration acceleration in the longitudinal, a_z, direction (foot-to-head direction) (see figure 1). Values define the TLV in terms of rms value pure (sinusoidal) single frequency vibration or of rms value in one-third-octave band for distributed vibration. (Adapted from ISO 2631)

Frequency	Acceleration, m/s² Exposure Times								
Hz	24 h	16 h	8 h	4 h	2.5 h	1 h	25min	16min	1min
1.0	0.28	0.383	0.63	1.06	1.40	2.36	3.55	4.25	5.60
1.25	0.25	0.338	0.56	0.95	1.26	2.12	3.15	3.75	5.00
1.6	0.224	0.302	0.50	0.85	1.12	1.90	2.80	3.35	4.50
2.0	0.22	0.27	0.45	0.75	1.00	1.70	2.50	3.00	4.00
2.5	0.18	0.23	0.40	0.67	0.90	1.50	2.24	2.65	3.55
3.15	0.16	0.212	0.355	0.60	0.80	1.32	2.00	2.35	3.15
4.0	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
5.0	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
6.3	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
8.0	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
10.0	0.18	0.239	0.40	0.67	0.90	1.50	2.24	2.65	3.55
12.5	0.224	0.302	0.50	0.85	1.12	1.90	2.80	3.35	4.50
16.0	0.28	0.383	0.63	1.06	1.40	2.36	3.55	4.25	5.60
20.0	0.355	0.477	0.80	1.32	1.80	3.00	4.50	5.30	7.10
25.0	0.45	0.605	1.00	1.70	2.24	3.75	5.60	6.70	9.00
31.5	0.56	0.765	1.25	2.12	2.80	4.75	7.10	8.50.	11.2
40.0	0.71	0.955	1.60	2.65	3.55	6.00	9.00	10.6	14.0
50.0	0.90	1.19	2.00	3.35	4.50	7.50	11.2	13.2	18.0
63.0	1.12	1.53	2.50	4.20	5.60	9.50	14.0	17.0	22.4
80.0	1.40	1.91	3.15	5.30	7.10	11.80	18.0	21.2	28.0

TABLE 4: Numerical values for vibration acceleration in the transverse, a_x, or a_y direction (foot-to-chest or side to side) (see figure 2). Values define the TLV in terms of rms value pure (sinusoidal) single frequency vibration or of rms value in one-third-octave band for distributed vibration. (Adapted from ISO 2631)

Frequency	**Acceleration, m/s² Exposure Times**								
Hz	24 h	16 h	8 h	4 h	2.5 h	1 h	25min	16min	1min
1.0	0.10	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.00
1.25	0.10	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.00
1.6	0.10	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.00
2.0	0.10	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.00
2.5	0.125	0.171	0.280	0.45	0.63	1.06	1.60	1.90	2.50
3.15	0.16	0.212	0.355	0.56	0.80	1.32	2.00	2.36	3.15
4.0	0.20	0.270	0.45	0.71	1.00	1.70	2.50	3.00	4.00
5.0	0.25	0.338	0.56	0.90	1.25	2.12	3.15	3.75	5.00
6.3	0.315	0.428	0.71	1.12	1.60	2.65	4.00	4.75	6.30
8.0	0.40	0.54	0.90	1.40	2.00	3.35	5.00	6.00	8.00
10.0	0.50	0.675	1.12	1.80	2.50	4.25	6.30	7.50	10.0
12.5	0.63	0.855	1.40	2.24	3.15	5.30	8.00	9.50	12.5
16.0	0.80	1.06	1.80	2.80	4.00	6.70	10.0	11.8	16.0
20.0	1.00	1.35	2.24	3.55	5.00	8.50	12.5	15.0	20.0
25.0	1.25	1.71	2.80	4.50	6.30	10.6	15.0	19.0	25.0
31.5	1.60	2.12	3.55	5.60	8.00	13.3	20.0	23.6	31.5
40.0	2.00	2.70	4.50	7.10	10.0	17.0	25.0	30.0	40.0
50.0	2.50	3.38	5.60	9.00	12.5	21.2	31.5	37.5	50.0
63.0	3.15	4.28	7.10	11.2	16.0	26.5	40.0	45.7	63.0
80.0	4.00	5.40	9.00	14.0	20.0	33.5	50.0	60.0	80.0

2) Vobration acceleration is a vector with magnitude expressed in units of m/s^2. The gravitational acceleration "g" equals 9.81 m/s^2. Figure 3 and 4 above show daily exposure time-dependent curves. They indicate that human vibration resonance occurs in the 4 to 8 Hz frequency range for the Z axis and in the 1 to 2 Hz frequency range for the X and Y axes, where the axes are defined in figure 5.

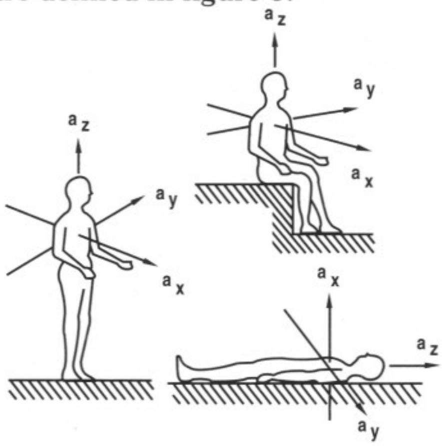

Figure 5 : Biodynamic coordinate system acceleration measurements (adapted from ISO 2631). a_x ,a_y, a_z = acceleration in the direction of the x, y, and z axes.

3) The TLVs are valid from crest factors of 6 or less. The crest factors is defined as the ratio of peak to rms acceleration, measured in the same direction, over a period of one minute for any of the orthogonal X, Y,and Z axes. The TLVs will underestimate the effects of whole-body vibration, and must be used with caution when the crest factors exceeds 6.

4) Measurement procedures and data analysis for whole-body vibrations are summarised as follow:

i) At each measurement point, three orthogonal, continuous rms acceleration measurements are to be simultaneously made and recorded for at least one minute along the biodynamic coordinates as shown in figure 5.

ii) Three light-weight accelerometers, each with a cross-axis sensitivity of less than 10%, are to be perpendicularly mounted to a light-weight metal cube and placed in the center of a hard rubber disc. The total weight of the disc, cube, accelerometers, and cable shall not exceed 10 % of the total weight of the object to be measured. Measurements are made by placing the instrumented rubber disc on the top of the drives buttocks, as the vehicle is operated.

iii) For each measurement axis, a1/3 octave band (1 to 80 Hz) vibration frequency spectrum analysis using a FFT analyser is required for comparison to figure 3, as appropriate.

iv) If the rms acceleration of any of the spectral peaks equals or exceeds the values shown in figure 3 or figure 4 for the relevant time periods, the TLV is exceeded for that exposure time. The axis with the highest spectral peak intersecting the curve with the shortest exposure time dominates, and determines the permissible exposure.

5) The total weighted rms acceleration for each axis can be calculated using equation 1 below with the appropriate axis weighting factors taken from table 5. For the X axis (analogous equations and definitions apply to the Y and Z axis), the equation is:

$$A_{wt} = \sqrt{\Sigma(W_{fx}A_{fx})^2} \quad \text{------ Equation 1}$$

Where: A_{wt} = total weighted rms acceleration for the X axis

W_{fx} =weighted factors for the X axis each 1/3 octave band frequency from 1 to 80 Hz (Table 5)

A_{fx} = rms acceleration value for the X axis spectrum at each 1.3 octave band frequency from 1 to 80 Hz

6. If the vibration axes have similar acceleration magnitudes as determined by equation 1, the combined motion of all three axes could be greater than any one component and could possibly affect vehicle operator performance. Each of the component result determined by equation 1 may be used in equation 2 to find the resultant overall weighted total rms acceleration, A_{wt}:

$$A_{wt} = \sqrt{(1.4A_{wx})^2 + (1.4A_{wy})^2 + (A_{wz})^2} \text{ ----- Equation 2}$$

The factor of 1.4 multiplying the X and Y total weighted rms acceleration values is the ratio of the values of the longitudinal and transverse curves of the equal response in the most sensitive human response ranges.

The European Commission (EC) recommendeds $0.5 m/s^2$ as an action level for an 8 hour per day overall weighted total rms acceleration.

TABLE 5 : Weighting factors relative to the frequency range of maximum acceleration sensitivity for the response curves of figures 3 and 4. Adapted from ISO 2631.

	Weighting factor for	
Frequency Hz	**Longitudinal Z vibrations (Figure 1)**	**Tranverse X, Y vibrations (Figure 2)**
1.00	0.50	1.00
1.25	0.56	1.00
1.60	0.63	1.00
2.00	0.71	1.00
2.50	0.80	0.80
3.15	0.90	0.63
4.00	1.00	0.50
5.00	1.00	0.40
6.30	1.00	0.315
8.00	1.00	0.25
10.0	0.80	0.20
12.5	0.63	0.16
16.0	0.50	0.125
20.0	0.40	0.10
25.0	0.315	0.08
31.5	0.25	0.063
40.0	0.20	0.05
50.0	0.16	0.04
63.0	0.125	0.0315
80.0	0.10	0.025