Best Practices – Vibration at the Work Site

Government of Alberta
Employment and Immigration

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This guide was prepared to help you understand vibration hazards in the workplace, and to provide guidance on how to identify, assess, and control vibration hazards.

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This section outlines ways in which vibration is generated and transmitted, the types of vibration exposure – hand-arm and whole body – and potential health impacts of overexposure to vibration.

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Section 6 presents a survey of methods for reducing whole body exposure, and lessening the impacts of exposure.

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This section provides an overview of occupational health and safety laws in Alberta, Canada, and internationally relating to the assessment and control of vibration exposure. It also gives an overview of key voluntary standards relating to vibration exposure assessment and control, and design for minimizing vibration.

Glossary of Terms

Acceleration – The capacity to gain speed. In reference to vibration, it is one of the main items that determines exposure hazard to a worker.

Acute Health Effect – A health effect with an quick onset.

Amplitude – Greatness of size. In terms of vibration, it is the maximum extent of an oscillation.

Chronic Health Effect – A health effect marked by a long duration or frequent reappearance.

Cycle – A group of events which happen in a particular order, one following the other, and which are often repeated.

Cycles per Second – Cycles occurring in each second.

Damping – A way of spreading out the energy in a vibrating system to reduce its effect(s).

Digital Arteries – Arteries relating to a finger or fingers.

Digital Artery Thrombosis – A local clotting of the blood in a digital artery.

Distal – A part situated away from the centre of the body or point of attachment. (e.g. the tip of the finger is the distal part of the finger because it is the furthest part of the finger away from the centre of the body)

Exposure Action Value – Limit set for occupational exposure. Above this value, employers must take steps to reduce exposure levels.

Exposure Limit Value - Maximum occupational exposure limit.

Frequency – The number of repetitions in a given time, especially per second. In relation to vibration , it is the rate of reappearance of a vibration

Hand-Arm Vibration – Vibration that is transmitted through the hands and the forearm.

Hand-Arm Vibration Syndrome – A collection of signs and symptoms resulting from exposure to hand-arm vibration.

Hertz (Hz) – The System International (SI) unit of frequency. A Hertz is equal to one cycle per second.

Isolation – The act of isolating; the state of being separated.

Ligaments – A short band of tough flexible fibrous connective tissue linking bones together.

Median Nerve – A nerve that passes through the carpal tunnel and can be damaged by repeated trauma during the gripping of some handheld vibrating equipment.

Musculoskeletal Disorder (Musculoskeletal Injury (MSI)) – Diseases of the muscles and their associated ligaments and other connective tissues.

Oscillating Movement – Movement to and fro between points with regularity.

Posture – A position of a person's body when sitting or standing.

Power Grip – A grip with strong mechanical force.

Proximal – A part situated closest to the centre of the body or point of attachment (e.g. the shoulder is the most proximal part of the arm because it is closest to the centerline of the body).

Raynaud's Phenomenon – A condition characterized by spasms of arteries, especially the fingers, leading to paleness, pain, numbness and in severe cases tissue death.

Reciprocal Movement – Movement back-and-forth or up-and-down.

Repetitive Motion Injuries – Injury caused by extended repeated use of specific muscles, for example keyboarding.

Rotational Movement – Movement around a centre axis.

Segmental Vibration – Vibration of the hands, arms, legs, or a specific part of the body without causing whole body vibration.

Static Posture – A fixed unmoving posture.

Stockholm Scale – A scale for classifying cold-induced Raynaud's phenomenon in hand-arm vibration syndrome.

Stockholm Workshop Classification System for Vibration-Induced White Finger – Same as the Stockholm Scale.

Tendons – A cord or strand of strong fibrous tissue attaching a muscle to a bone.

Threshold Limit Value – A term used by the American Conference of Governmental Industrial Hygienists to define the reasonable level of a hazard to which a person can be exposed without adverse health effects.

Thrombosis – Local clotting of the blood in a part of the circulatory system.

Torque – A twisting or rotating force.

Ulnar Artery – Artery near to the ulna, the bone extending from the elbow to the wrist on the side opposite to the thumb in humans.

Ulnar Artery Thrombosis (or hypothenar hammer syndrome) – Local clotting of the blood in the ulnar artery.

Vibrate – Move with small movements rapidly to and fro. Oscillate.

Vibration – The state of vibrating. A continuous rapid shaking movement or sensation.

Vibration-Induced White Finger – Physiological condition resulting in whitening of one or more fingers upon exposure to vibration.

Viscoelastic – Material that has both elastic and sticky behaviour.

Whole Body Vibration – Vibration exposure affecting the entire body.

Section 2: Introduction to Vibration

2.1 What is Vibration?

An object "**vibrates**" when it moves back and forth, up and down, or side to side, usually very rapidly. "**Vibration**" describes the physical energy from a vibrating object, and also what we feel when that energy is transmitted to us. The key terms used to describe this movement are "**frequency**" and "**amplitude**".

"Frequency" describes the number of vibrating movements in a given time period. Frequency is measured in "**cycles per second**" or **hertz (Hz)**. An object vibrating with a frequency of one hertz completes one full vibrating cycle over one second. A "**cycle**" is the complete pattern of movement of the vibrating object from start to finish.

"**Amplitude**" is the intensity or magnitude of vibration. It is measured as the maximum distance an object moves from a central point. Amplitude is measured in metres (m).

Figure 1 illustrates these concepts of frequency, amplitude and cycle, using a wave pattern.

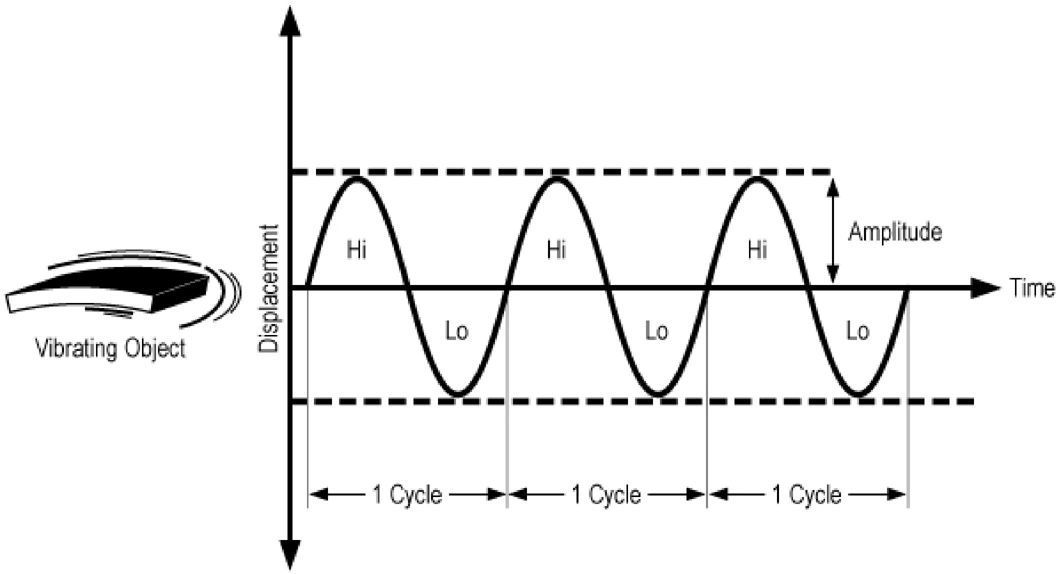

Figure 1: Cycle, Frequency and Amplitude
(Adapted from *Occupational Vibration Exposure,* Pathak 2005)

"**Cycle**" is the movement of the wave from its starting position at "A" along the horizontal line to the point where it returns to a new starting position at "B".

"**Frequency**" is the number of cycles that occur during a defined time period. If the end of the first cycle at "B" occurs 1 second after the start of the first cycle at "A", then 1 cycle has been completed in 1 second. 1 cycle per second equals 1 Hertz. If on the other hand, the end of the third cycle at "C" occurs 1 second after the start of the first cycle at "A", then 3 cycles have been completed in 1 second. 3 cycles per second equals 3 Hertz.

"**Amplitude**" is the distance from the centre point of movement to the peak (or trough).

A wave pattern is often used to describe what vibrating objects look like, but the actual physical movement of the vibrating object can have many patterns. For example:

- up and down ("**reciprocal movement"**) – like the bit of jackhammer, or a piston
- around and around (**"rotational movement"**) – like a drill or drive shaft
- back and forth ("**oscillating movement**") – like a pendulum, or a paint can shaker

2.2 How Vibration Exposure Occurs

Vibration exposure occurs when a vibrating object, such as a machine, tool or surface, transmits vibration energy to a person's body. For this to occur, a part of the person's body must either be in direct contact with the vibrating object, or another object that is itself making contact with the vibrating object, as shown in Figure 2.

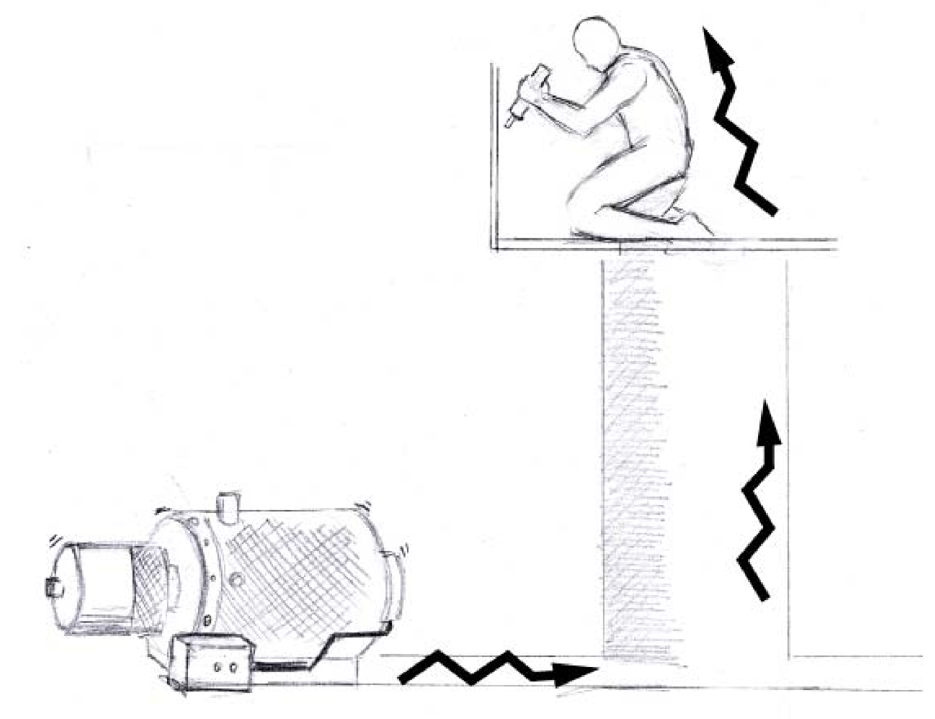

Figure 2: Diagram illustrating transmission of vibration from a motor through a wall to a platform, resulting in whole body vibration exposure

2.3 Types of Vibration Exposure

There are two types of vibration exposure that are of interest: "**segmental vibration**" exposure, and "**whole body vibration**" exposure. **Segmental vibration exposure** refers to exposure that is mainly transmitted to, and concentrated on, a specific part of the body – such as the hand, arm, or leg. **Whole body vibration exposure** is when vibration is transmitted throughout all or most of the body.

2.3.1 Hand-Arm Vibration Exposure

Hand-arm vibration is the most common form of segmental vibration experienced in work settings. Hand-arm vibration occurs when a person holds or guides a vibrating tool or machine with their hand or hands, and vibration is transmitted from the tool to the hand(s) and along the arm(s).

A person's exposure to hand-arm vibration and the health impacts of exposure can be influenced by many factors, such as:

- the temperature of the area the person is working in
- whether or not the person is wearing gloves

- how the tool is gripped
- the frequency and amplitude of the vibration
- how long and how often exposure occurs

Hand-arm vibration exposure can happen in many different jobs such as:

- building and maintenance of roads and railways
- construction and demolition
- maintenance of parks and groundskeeping
- forestry
- foundries
- heavy engineering
- manufacturing concrete products
- mines and quarries
- motor vehicle and equipment manufacture and repair
- meat cutting
- oil well drilling and servicing
- public utilities (e.g. water, gas, electricity, telecommunications)

There are hundreds of different kinds of hand-held power tools and equipment that can produce hand-arm vibration exposures that can cause adverse health effects, including:

- chainsaws
- jackhammers
- concrete and masonry saws
- hammer drills
- hand-held grinders
- powered sanders
- impact wrenches
- riveting tools
- chipping tools
- jigsaws
- needle scalers
- pedestal grinders
- polishers
- power hammers
- power chisels
- gas and electric powered lawn mowers
- brush cutters
- grass trimmers
- hedge trimmers

- ground tampers / compactors
- snow blowers
- hand-guided soil tillers / cultivators
- needle guns / needle scalers
- concrete vibrators
- concrete finishers
- floor sanders
- floor polishers
- hand-guided road sweepers
- power washers

Figure 3 shows typical hand-arm vibration exposures from various types of hand-held tools. The 25th percentile means that 25% of exposures will be below this level and the 75th percentile means that 75% of exposures will be below this level. The minimum and maximum values are the lowest and highest vibration levels that are typical for the tool represented.

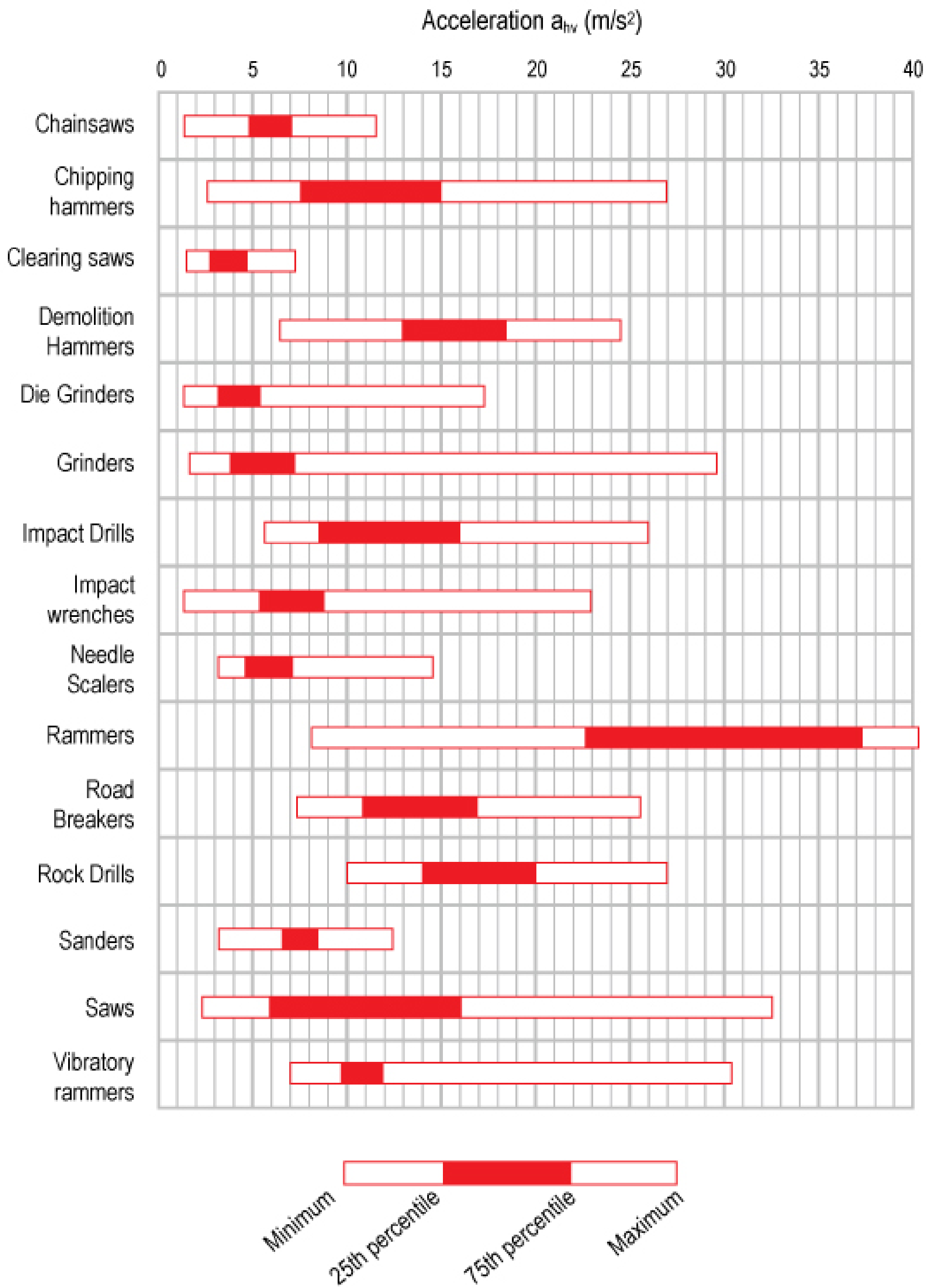

Figure 3 - Typical Hand-Arm Vibration Intensities for Various Hand-Tools
(Data from the *Hand-Arm Vibration Guide*, Griffin et al, 2006)

2.3.2 Whole Body Vibration Exposure

Whole body vibration occurs when a person stands or sits on a vibrating vehicle, machine or surface. The vibration is transmitted through supporting surfaces such as the standing person's feet, the buttocks of a seated person, and the supporting areas of a reclining person.

Whole body vibration exposure often comes from a variety of different vibration sources from one or more components of a machine, vehicle or surface. These sources can include:

- engines and engine parts
- movement of gears and transmissions
- rotation of tires, wheels and axles
- movement of the vehicle over irregular surfaces.

Table 1 lists some sources of exposure to whole body vibration.

Table 1 – Typical Sources of Whole Body Vibration	
• Mobile Crane	• Long haul transport
• Dump truck	• Backhoe
• Surface haulage truck	• Bulldozer
• Mining vehicles	• Excavator
• Lift truck	• Compactor
• Skid Steer Loader	• Grader / Scraper
• Zoom boom	• Farm tractors and similar vehicles
• Bus	• Railway vehicles
• Helicopter	• Large static production machines used for compaction, hammering, punching
• Fast boat	
• Large fuel-fired electrical generators	

Whole body vibration exposure often involves exposure to several frequencies and amplitudes at the same time, as shown in Figure 4. Each vibration wave shown in the figure represents a different vibration source; each vibrating source can have unique vibration characteristics (i.e. different frequencies and amplitudes).

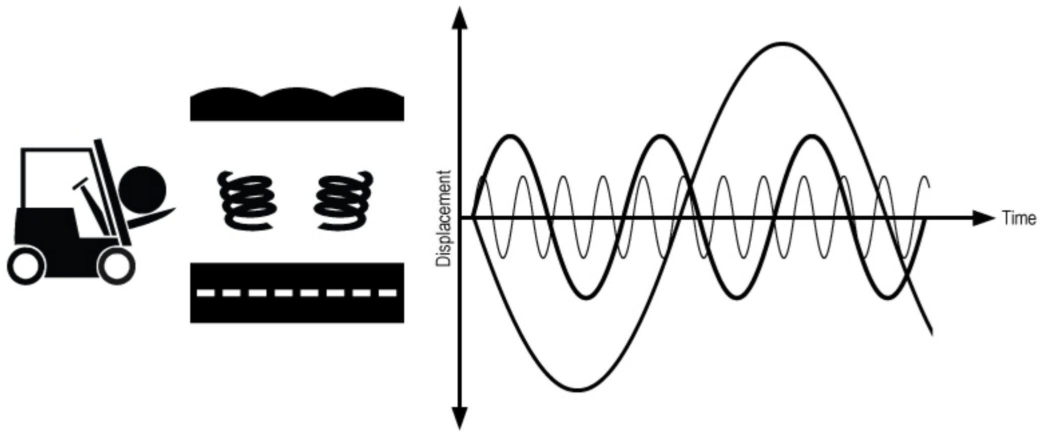

Figure 4 – Whole Body Exposure to Multiple Vibration Frequencies and Amplitudes

How the body responds to whole body vibration depends on the frequency of the vibration, the acceleration of the vibration and the length of exposure.

Figure 5 shows typical amounts of whole body vibration experienced by operators of various types of mobile equipment. The mean acceleration is the amounts of vibration. Higher mean accelerations mean that mobile equipment operators are exposed to more vibration and are at more risk of experiencing health hazards.

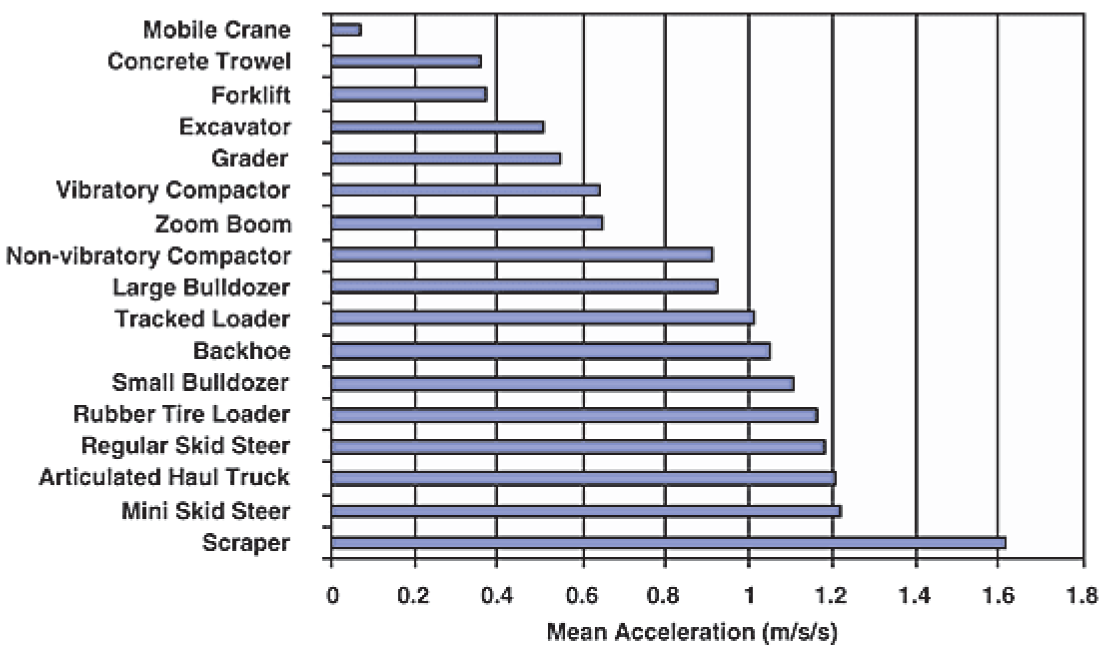

Figure 5 – Typical Whole Body Vibration Exposures for Various Types of Mobile Equipment (Data From Construction Safety Association of Ontario)

2.4 How Much Exposure is Too Much?

Exposure to hand-arm and whole body vibration is measured in units of **acceleration**. Acceleration is the rate of change in speed of an object. The units used are “metres of distance per second per second”.

The International Organization for Standardization (ISO), the American Conference of Governmental Industrial Hygienists (ACGIH®), and the European Committee for Standardization (CEN) have developed standards and threshold limit values (TLVs®), which are considered to be health-based recommended maximum exposure levels. The ISO standard deals with whole body vibration only, while ACGIH® and CEN provide limits for both hand-arm and whole body vibration. The standards are fairly complex, and the measurement of exposure and evaluation of exposures against the standards requires specialized equipment and expertise.

Certain factors such as the way a tool is used, the characteristics of the tool or equipment, the environment in which the tool or equipment is used, protective practices used, etc. affect a worker’s susceptibility to vibration. These are discussed in more detail in Section 3.

2.5 How Many People are Affected by Occupational Vibration Overexposure?

Most public and private workers’ compensation organizations in Canada, the United States and Europe do not yet have specific statistics on the number of claims for injuries and illnesses caused uniquely by vibration exposure. Consequently, there are no good statistics on how common vibration-induced illnesses and injuries are.

However, as a result of the implementation of workplace vibration regulations and prevention programs in the United Kingdom, estimates have been produced for that jurisdiction. These figures convey a sense of the potential magnitude of the health impact resulting from vibration overexposure:

- It is estimated that up to 300,000 working days are lost each year in the United Kingdom due to hand-arm disability related absences.
- In the United Kingdom, a survey by the Industrial Injuries Disability Benefit in 2005/2006 determined a prevalence of 545 cases of vibration white finger out of a total 1880 reported non-lung industrial diseases. This means that 29% of the total non-lung industrial disease cases were classified as vibration white finger injuries (HSE, 2007).

- A survey in 1997-98 by the UK Medical Research Council estimated that there were 288,000 vibration white finger sufferers in Great Britain.
- On the basis of the findings of a large scale questionnaire survey, Palmer et al (2000) estimated that about 2% of the population of Great Britain (over 1 million people) are periodically exposed to high levels of hand-arm vibration in the workplace. Close to 20% of the population (nearly 10 million people) are regularly exposed to high levels of whole body vibration.

Various researchers have also looked at the prevalence of vibration-related conditions in workers:

- A study by Nyantumbu et al (2007) found that 15% of gold miners in South Africa had symptoms of hand-arm vibration syndrome.
- A study by Bovenzi (1994) found that 31% of a large population of stonecutters in Italy had symptoms of hand-arm vibration syndrome.
- Lawson and McGeoch (2003) reported that an assessment of former coal miners in the United Kingdom for purposes of disability compensation found 95% to have symptoms of vibration white finger.

On the whole, these figures suggest that the size of the working population exposed to vibration is very high. In heavily exposed occupations, the prevalence of vibration-related disorders is also high.

Section 3: Vibration Health Effects

3.1 Hand-Arm Vibration Syndrome

3.1.1 Overview

Hand-arm vibration syndrome is a collection of symptoms caused by vibration transmitted into the hands and arms through the palms and fingers. It develops in workers who use hand-held power work equipment. Other common names for hand-arm vibration syndrome are:

- Raynaud's phenomenon of occupational origin
- secondary Raynaud's phenomenon
- vibration white finger
- dead finger
- vibration syndrome.

The syndrome affects the nerves, blood vessels, muscles, and joints of the hand, wrist and arm. It can become very disabling if early symptoms are ignored and vibration exposure continues. Typical symptoms of hand-arm vibration syndrome include:

- occasional numbness in fingers
- tingling in fingers
- blanching (whitening) of fingers
- pain when exposed to cold
- pain when blood circulation returns to the fingers
- reduced grip strength
- reduced finger dexterity.

3.1.2 Vascular Disorders

Raynaud's phenomenon is the most common health effect from hand-arm vibration. The small blood vessels of the hand narrow, reducing blood flow through the hands and fingers. The fingers become white, cold and numb. This effect can last for minutes or up to an hour after exposure to vibration.

Raynaud's phenomenon can range from mild to very severe. The condition is classified into four stages known as the "Stockholm Scale", as shown in Table 2.

Table 2 - Stockholm Scale for the Classification of Cold-Induced Raynaud's Phenomenon in Hand-Arm Vibration Syndrome (Scale from ***Hand-Arm (Segmental) Vibration, ACGIH, 2009, Table 2, pg.204)***		
Stage	**Symptom Severity**	**Description**
0	None	No Symptoms
1	Mild	Occasional attacks affecting only the tips of one or more fingers
2	Moderate	Occasional attacks affecting distal and middle (rarely also proximal) bones of one or more fingers
3	Severe	Frequent attacks affecting all bones of most fingers
4	Very Severe	As in stage 3, with skin changes in the fingertips

In very serious cases, permanent damage can affect blood flow to the worker's fingers. The fingers may turn a dark and blue-black colour, develop open sores, and even become gangrenous.

Other conditions from hand-arm vibration exposure include blood clotting in the arteries of the arm and fingers (ulnar artery thrombosis and digital artery thrombosis). In each case, a clot forms in the artery, blocking blood flow. Symptoms of artery thrombosis depend on the degree of blood flow obstruction caused by the clot. Where the clot is small and causes insignificant blood flow reduction, there may be no symptoms at all. As clot size and degree of blood flow obstruction increases, symptoms become more severe, and can include whiteness of the skin, coldness, numbness, pain, weakness, and loss of function.

3.1.3 Nerve Disorders

Hand-arm vibration syndrome can also affect the nerves of the hands and arms. Affected workers sense tingling and numbness in their fingers and hands, their sense of touch and temperature may be reduced, and their manual dexterity may be affected. Symptoms have been categorized as shown in Table 3:

Table 3 - Stockholm Scale for Classification of Cold-Induced Raynaud's Phenomenon in Hand-Arm Vibration Syndrome (Scale from ***Hand-Arm (Segmental) Vibration, ACGIH, 2009, Table 2, pg. 204)***	
Stage	**Description**
0 SN	Exposed to vibration but no symptoms
1 SN	Intermittent alternating periods of numbness, with or without tingling
2 SN	Intermittent alternating periods of or persistent numbness, lessened touch sensation
3 SN	Intermittent alternating periods of or persistent numbness, lessened touch sensation, and/or ability to move the hands and fingers

Carpal tunnel syndrome is not included in the definition of hand-arm vibration syndrome but often occurs in workers with hand-arm vibration syndrome. It is a nerve disorder that causes pain, tingling, numbness, abnormal skin sensations and weakness in parts of the hand and forearm. It occurs when the median nerve is compressed at the wrist.

3.1.4 Musculoskeletal Injury

Hand-arm vibration can also damage the muscles and bones in the wrist and arms. The wrist and elbow may develop swollen and painful joints (osteoarthritis) and some tissues at tendon attachment sites may harden (ossify). Symptoms include loss of strength in the hands and pain in the arms and wrists. In the later stages, the affected worker may experience loss of hand function and necrosis (tissue death) of the fingers.

Dupuytren’s contracture is a disease of tissues in the palm of the hand that is associated with vibration. Tissues under the palm of the hand thicken and shorten such that the tendons connected to the fingers cannot move freely and the fingers cannot be straightened.

Tendonitis (inflammation of the tendons) and inflammation of the sheaths in the upper limbs may also develop from the use of hand-held power tools. Tendonitis is thought to be a result of poor hand tool ergonomics rather than a direct result of vibration exposure. However, since workers using powered hand-tools do not always use the best ergonomic methods, tendonitis is often associated with hand-arm vibration syndrome.

The onset of hand-arm vibration syndrome symptoms may be anywhere from a few months to several years after initial exposure. In the early stages, symptoms may be reversible if exposure is reduced or eliminated. However, as the length of exposure increases, there is greater potential for more damage. Later stage health effects are often irreversible.

3.1.5 Factors Affecting Risk of Hand-Arm Vibration Syndrome

There are a number of factors that affect:

- the risk of developing hand-arm vibration syndrome,
- how quickly symptoms appear,
- the speed of onset and
- the severity of symptoms.

These are listed in Table 4.

While many factors are associated with vibration-related disorders, exposure time and intensity provide the greatest predictors of the risk to worker health and how severe the symptoms of exposure will be.

Table 4 - Factors Affecting Risk of Hand-Arm Vibration Syndrome	
Category	**Factor**
Exposure Frequency	- Frequency of vibration worker is exposed to
Exposure Time	- Length of time tool is in use each day - Total working hours of exposure
Tool Use Variables	- Ergonomics of tool use (lifting, posture, repetitive movements, position of hand and arm relative to the body) - Surface area, location and mass of parts of the hand in contact with the source of vibration - Grip forces - Operator control of the tool
Tool Characteristics	- Impact (higher vibration) vs. non-impact - Weight of the tool - Operating speed - State of tool maintenance - Texture of tool handle (soft vs. rigid) - Shape of tool handle
Environment	- Exposure to cold ambient temperatures - Exposure to psychosocial aspects (e.g. events at home, relationships) - Exposure to other physical and chemical agents
Vibration Parameters	- Frequency, amplitude and direction of vibration - Area of the contact surface between the vibration source with the hand - Level of acceleration produced by the tool (vibration energy)
Worker	- Clothing - Body size - Posture - Body tension - Body composition - Medical history - Susceptibility to vibration - Smoking and use of drugs - Skill and productivity - Disease or prior injury to the fingers and hands - Number of years of use with tool
Protective Practices	- Anti-vibration materials in use (e.g. gloves, boots) - Work rest periods
Material	- Hardness of material being contacted (e.g. metal for grinding)

3.2 Whole Body Vibration

Whole body vibration exposure occurs when vibration is transmitted from machines, vehicles or surfaces through the bones of the lower pelvis during sitting or through the feet and legs of a worker who is standing or sitting. Most of the time vibration is absorbed by the body without harmful effects. However, frequencies between 1 and 20 Hz cause the pelvis and spine to resonate and can lead to many health effects. Vehicles and industrial machinery often vibrate with frequencies in the range where human resonance occurs (4-8 Hertz).

Common acute health effects from short-term exposure to whole body vibration include:

- headache
- chest pain
- abdominal pain
- nausea
- fatigue
- vertigo (loss of balance)

It is believed that nausea, fatigue and vertigo may be due to vibration affecting the inner ear which controls balance. Headache, chest pain and abdominal pain may be due to increased blood pressure, which may be an involuntary response to whole body vibration, or a result of bracing to resist vibration.

Symptoms of acute exposure generally end within minutes or hours of when exposure stops.

Common chronic health effects from long-term exposure include:

- lower back pain
- damage to the spine
- major curves in middle-lower portion of the spine (lumbar scoliosis)
- deterioration of the discs in between the vertebrae of the spine (disc disease)
- tears or damage to the discs in between the vertebrae of the spine (herniated discs)
- neck problems[1]

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[1] While neck and shoulder disorders are also commonly associated with exposure to whole body vibration, it is not certain whether these conditions are due entirely to vibration exposure. Workers exposed to whole body vibration often perform tasks that involve poor posture, extended time sitting in unnatural postures, frequent twisting of the spine, frequent lifting of heavy materials, and unexpected movements. These factors could contribute to neck and shoulder disorders.

- hearing loss
- sleeping disorders.

The musculoskeletal symptoms from vibration are likely due to inflammation and trauma to the spine. Vibration exposure can produce hearing loss in the same way that noise exposure does – by over-stimulation of inner ear auditory hair cells. Sleeping disorders could be due to discomfort from musculoskeletal disorders, or could be a direct effect of vibration exposure.

The risk to health increases with increasing exposure. The progress and severity of symptoms also depends on the magnitude, frequency, and direction of the vibration. Chronic symptoms often persist for long periods (weeks, months, years) after exposure ends, and are usually permanent.

Section 4: Identifying and Assessing Vibration Exposures

This section describes methods for identifying and assessing exposures to hand-arm and whole body vibration. These methods help to judge the potential for harmful exposures and to determine the need for reducing exposure.

4.1 Step 1: Identify Activities Causing Vibration Exposure

The first step in assessing vibration exposure is to identify the activities that lead to vibration exposure. To do so, hold discussions with workers and supervisors, and observe work activities to develop an understanding of:

- work operations
- tasks performed
- tools and equipment used
- vehicles used
- platforms or other surfaces workers stand on that may transmit vibration from stationary equipment.

Table 5 can be used to help in the identification of tools and equipment used by workers that can contribute to hand-arm and whole body vibration exposure.

4.2 Step 2: Estimate the Duration of Exposure

Once the work activities and equipment leading to vibration exposure have been identified, the next step is to determine the typical frequency (how often) and duration of vibration exposure. This is important in assessing vibration exposure risk because the potential for harm increases with the level and duration of vibration exposure.

Table 5 can also be used to record how often and for how long equipment or tools are used. Estimates can be obtained through discussions with workers and their supervisors, review of work activity records, and direct observation and timing of work activities.

Table 5 - Inventory of Vibration Exposure Sources

Vehicles in Use	Make / Model / Description	No. Units	How Often the Worker is Exposed	Duration of Operation	No. Exposed Workers
Backhoe loader					
Compactor - single drum					
Compactor - tandem					
Dozer					
Dumper					
Dumper - Articulated					
Excavator - Wheeled					
Excavator <25t					
Excavator >25t					
Farm Tractor					
Finisher / Asphalt Paver					
Forestry - Forwarder					
Forestry - Harvester					
Fork-lift Truck - Counterbalance					
Fork-lift Truck - Order Pickers					
Fork-lift Truck - Reach					
Grader					
Pallet-truck - ride-on vertical					
Scraper					
Tow Tractor					
Wheel Loader					
Other:					
Other:					
Other:					
Powered Hand Tools	**Make / Model / Description**	**No. Units**	**How Often the Worker is Exposed**	**Duration of Operation**	**No. Exposed Workers**
Brush Cutters					
Chainsaws					
Chipping Hammers					
Chisels					
Clearing Saws					
Compactors					
Cultivators / Tillers					
Demolition Hammers					
Die Grinders					
Grinders					
Hammer Drills					
Hedge Trimmers					
Impact Drills					
Impact Wrenches					
Lawn Mowers					
Needle Scalers					
Pedestal Grinders					
Powered Mowers					
Rammers					
Riveters					
Road Breakers					
Rock Drills					
Sanders					
Saws					
Snow Blowers					
Vibratory Rammers					
Other:					

4.3 Step 3: Use Published Data to Determine Potential Exposure Intensity

Many researchers have measured the hand-arm vibration exposures for a variety of hand-held and hand-guided tools (Figure 3), and whole-body vibration exposures (Figure 5) associated with the operation of different types of mobile and stationary equipment. In some European countries it has become mandatory for manufacturers to provide this information as part of the operator's manual.

As shown in Figures 3 and 5, vibration levels fall within a range of values. To estimate exposures the highest potential vibration intensity in the published range should be used unless it is certain that the vibration intensity of the tool in question is actually lower.

These sources of published information can be used to estimate the potential vibration exposure experienced by workers, and judge the need to reduce vibration exposures.

4.4 Step 4: Compare the Estimated Exposure to Recommended Maximum Permissible Exposure Limits

Once the exposure duration and the potential exposure intensity have been estimated, these values can be compared to maximum permissible vibration exposure limits, such as those suggested in the ACGIH®, CEN and ISO standards (see Section 7). If the estimated vibration exposure duration and intensity are higher than the suggested limits, then the actual vibration exposure could be unacceptably high.

4.5 Step 5: Implement Simple Vibration Controls

If vibration exposures might be too high, then steps should be taken to reduce exposures. The simplest way to reduce vibration exposure is to reduce the duration of time that the worker performs the work. However, reducing the amount of time the worker is exposed to vibration is not always possible. Workers may be under pressure to complete their work. In these cases, other vibration reduction methods should be explored. Table 6 identifies a variety of simple vibration reduction methods that should be considered where assessment identifies the potential for excessive vibration exposure.

Table 6 - Common Causes and Solutions to Vibration Problems

Possible Causes	Possible Solutions: Remove tool / vehicle from use	Balance vehicle tires	Sharpen equipment	Arrange for worker to alternate between vibrating and non-vibrating tool use	Instruct worker on ergonomic work practices	Instruct worker on proper use of personal protective equipment	Instruct worker on appropriate maintenance of equipment	Instruct worker to perform finger / hand and ergonomic exercises	Instruct worker to reduce the tool grip	Instruct worker to minimize duration of exposure to vibration	Alternate tasks for worker to minimize duration of exposure	Provide anti-vibration gloves	Provide cold weather clothing	Provide wind resistant clothing	Provide portable hand warmers	Provide water repellant outer layer clothing
Tool Design																
Manual warns of vibration hazard	•			•	•	•	•	•	•	•	•	•	•	•	•	•
Manual describes vibration control measures	•			•	•	•	•	•	•	•	•	•	•	•	•	•
Tool not designed for current use	•			•												
Vehicle not designed for roadway conditions	•															
Tool Maintenance																
Maintenance program absent		•	•				•									
Maintenance program not used		•	•				•									
Parts are wearing			•				•									
Parts are loose			•				•									
Blade / cutting edge dull			•				•									
Tool Use																
Wrist joint not at 90 degree angle				•	•			•		•	•					
Elbow joint not at 90 degree angle				•	•			•		•	•					
Shoulder joint not at 90 degree angle				•	•			•		•	•					
Tool positioned far from body				•	•			•		•	•					
Strong grip force required to stabilize tool				•	•			•	•	•	•	•	•	•	•	•
Sustained static postures				•	•			•		•	•					
Sustained stretched position				•	•			•		•	•					
Awkward posture for manual handling activities				•	•			•		•	•					
Hand in direct contact with				•		•		•	•	•	•	•	•	•	•	•

Table 6 - Common Causes and Solutions to Vibration Problems																
Possible Causes	Possible Solutions															
	Remove tool / vehicle from use	Balance vehicle tires	Sharpen equipment	Arrange for worker to alternate between vibrating and non-vibrating tool use	Instruct worker on ergonomic work practices	Instruct worker on proper use of personal protective equipment	Instruct worker on appropriate maintenance of equipment	Instruct worker to perform finger / hand and ergonomic exercises	Instruct worker to reduce the tool grip	Instruct worker to minimize duration of exposure to vibration	Alternate tasks for worker to minimize duration of exposure	Provide anti-vibration gloves	Provide cold weather clothing	Provide wind resistant clothing	Provide portable hand warmers	Provide water repellant outer layer clothing
vibrating surface																
Ambient Environment																
Exposure to shock / jolts during task				•		•		•	•	•	•	•	•	•	•	•
Off-road work required						•		•		•	•					
Cold temperature work required						•			•	•	•	•	•	•	•	•
Potholes or uneven road surfaces						•		•		•	•					

4.6 Step 6: Get Expert Assistance if Necessary

The vibration exposure assessment method described above may lead to the conclusion that exposure could be close to being, or is likely to be, excessive or cannot be determined. In these cases, expert assistance should be sought to either conduct measurements of vibration intensity to more conclusively determine the potential for adverse health effects; or recommend vibration-reducing control measures. Appendix 1 describes the methods that are used for measurement of vibration exposure.

4.7 Examples – Estimating Vibration Exposure

Here are two examples of how to make these estimates for hand-arm and whole body vibration exposure using published data.

4.7.1 Estimating Hand-Arm Vibration Exposure from Chain Saw Use

Step 1 - Identify the Vibration Sources: Crews of workers use chain-saws every day to trim tree branches that grow too close to power lines. Each crew consists of two workers, who share all duties. The only hand-held power tool that they use in their work is a chain saw.

Step 2 - Estimate the Exposure Duration*:* You have spoken with the workers, and observed their work operations, and you have found that during a typical day, each worker does the following activities for the times indicated:

Activity	Average Daily Duration (Hours)
Vehicle loading and inspection	0.25
Traveling from site to site in a boom truck	2
Breaks and lunch	1.25
Operating the boom and bucket	0.25
Fuelling and lubricating the chain saw	0.25
Operating the chain saw	3.5
Preparing work records	0.5

So, assuming that the only activity resulting in hand-arm vibration is operating the chain saw, then the total duration of hand-arm vibration exposure is 3.5 hours.

Step 3 - Use Published Data to Estimate Vibration Exposure Intensity*:* Using Figure 6, we see that chain saws have a wide range of vibration intensities – anywhere from as low as 1 m/s^2 to as high as 12 m/s^2. Figure 6 also shows that about 50% of all chain saw models fall in the range of about 5 m/s^2 to 7 m/s^2. So, we can do our exposure estimation in a variety of ways, using the lowest, middle, or highest vibration intensities. To be most cautious, we should use the highest vibration intensity, 12 m/s^2.

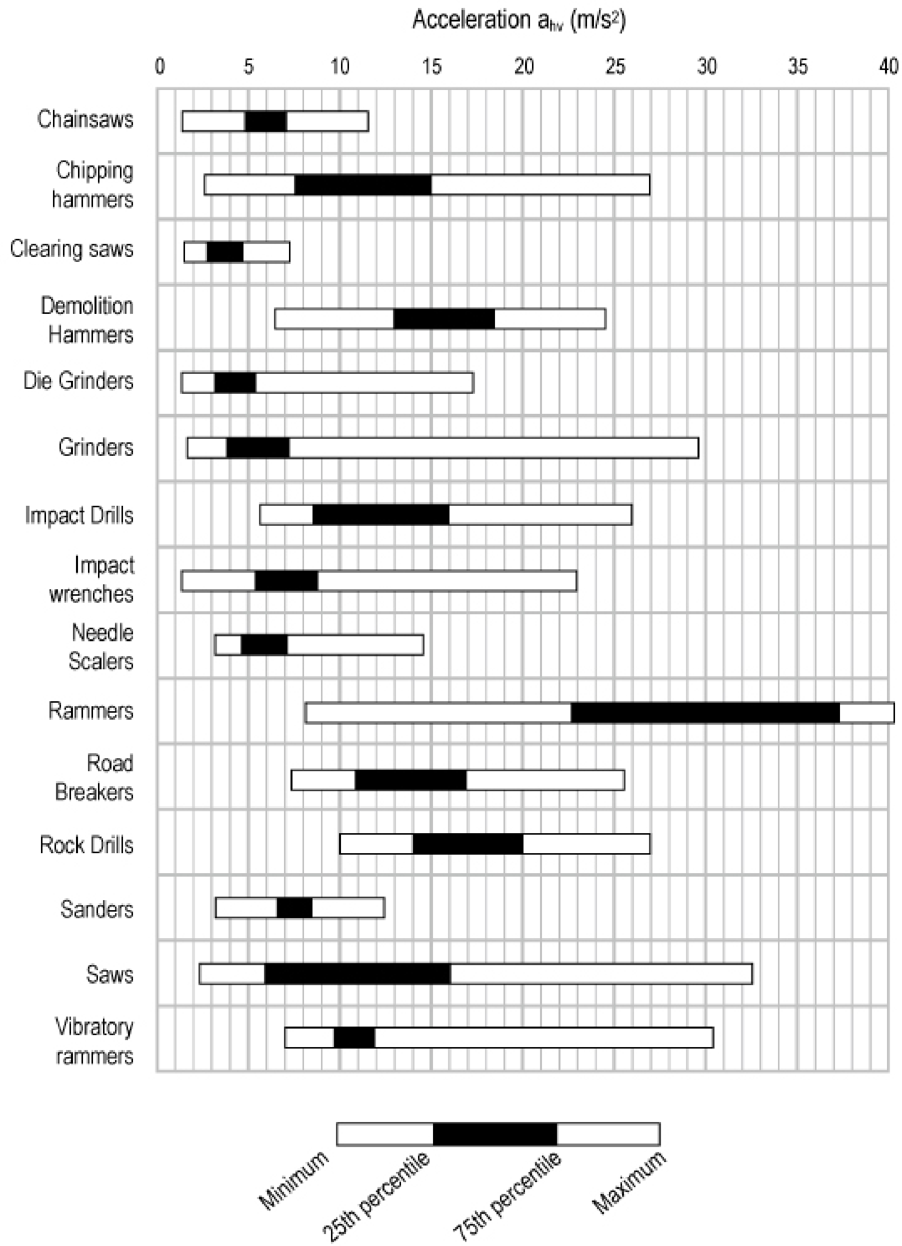

Figure 6 - Typical Hand-Arm Vibration Intensities for Various Hand-Tools (Data from the *Hand-Arm Vibration Guide*, Griffin et al, 2006)

Step 4 - Compare Exposure Levels to Maximum Permissible Exposure Limits: To this point, we have found that workers operating chain saws may be exposed for 3.5 hours per day to a vibration intensity as high as 12 m/s^2. We can now compare this to recommended maximum permissible exposure limits.

Table 7 shows ACGIH® exposure limits for hand-arm vibration.

Table 7 - ACGIH® Vibration Exposure Limits	
Exposure Duration (Hours)	**Maximum Vibration Amplitude (m/s^2)**
4 to 8	4
2 to 4	6
1 to 2	8
< 1	12

Under a worst-case scenario, the chain saws have a vibration intensity of 12 m/s^2. By ACGIH® recommendations, the chain saw should not be operated for more than 1 hour per day. If, instead, the chain saw is assumed to have a vibration intensity that is in the middle of the range, say 6 m/s^2, then the chain saw can be used from 2 to 4 hours per day, and our estimated daily duration of 3.5 hours of use would be acceptable.

Should this Vibration Exposure Be Considered Acceptable?: In this example, the actual vibration intensity of the chain saw is unknown, and there are large differences between the potentially lowest and highest vibration intensities. In a case such as this, it is best to either obtain information on the actual vibration levels from the chain saw manufacturer or consult an expert to conduct hand-arm vibration exposure measurements.

4.7.2 Estimating Whole Body Vibration Exposure from Operating Various Types of Construction Equipment

Step 1 - Identify the Vibration Sources: A construction company has backhoes and small bulldozers. It is determined that on a typical day, an operator will operate both a backhoe and a bulldozer. These pieces of equipment are the only sources of whole body vibration exposure.

Step 2 - Estimate the Exposure Duration: You have spoken with the operators, observed their work, and have found that over the course of a typical day, each operator does the following activities for the times indicated:

Activity	Average Daily Duration (Hours)
Vehicle fuelling, lubrication and inspection	0.5
Operating the backhoe	3
Breaks and lunch	1.25
Operating the small bulldozer	3
Preparing work records	0.25

So, there are two activities resulting in whole body vibration: backhoe operation (for <u>3 hours</u>), and bulldozer operation (for <u>3 hours</u>).

Step 3 – Use Published Data to Estimate Vibration Exposure Intensity: Using Figure 7, we can see that:

- the backhoe can produce whole body vibration exposure of about 1.05 m/s^2
- the small bulldozer can produce whole body vibration exposure of about 1.1 m/s^2

These are fairly similar vibration intensities for both types of equipment, so for simplicity we can say that the operator is exposed to whole body vibration of approximately 1 m/s^2 for 6 hours.

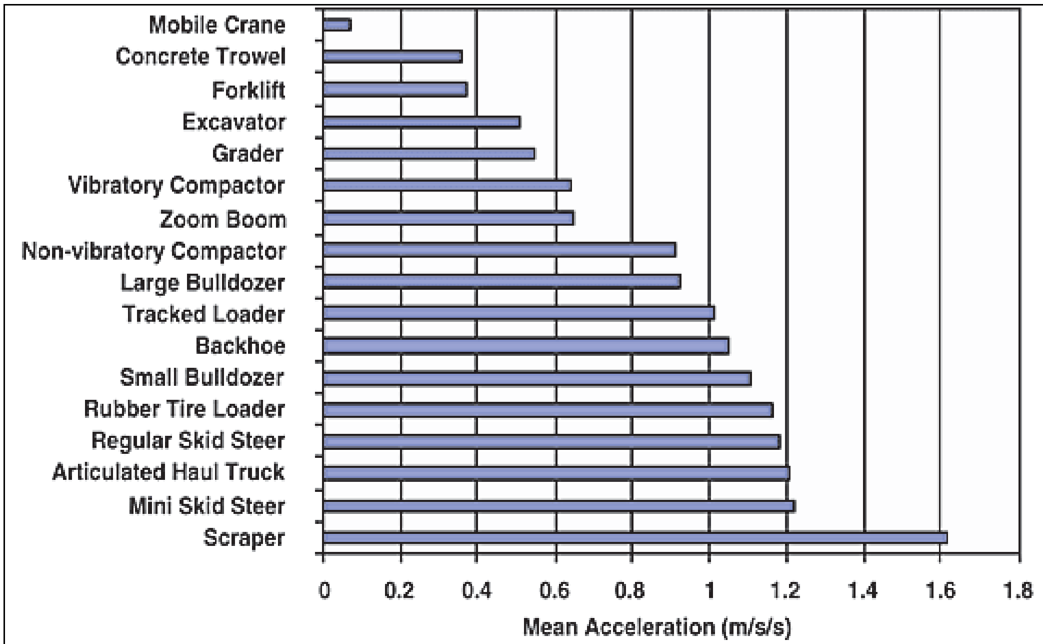

Figure 7 - Typical Whole Body Vibration Exposures for Various Types of Mobile Equipment (Data From Construction Safety Association of Ontario)

Step 4 - Compare Exposure Levels to Maximum Permissible Exposure Limits: To this point, we have concluded that the operators may be exposed for 6 hours per day to a vibration intensity of 1 m/s^2. We can now compare this to recommended maximum permissible exposure limits.

Table 8 shows CEN vibration exposure limits for whole body vibration.

Table 8 - European Vibration Directive Exposure Limits

Type	Daily Exposure Action Value (m/s^2)	Daily Exposure Limit (m/s^2)
Whole Body Vibration	0.5	1.15

By CEN recommendations, a worker's daily exposure to whole body vibration (i.e. exposure over an 8 hour day) should not exceed 1.15 m/s^2 .

Should this Vibration Exposure Be Considered Acceptable?: In this example, if the actual vibration intensity is about 1 m/s^2 for 6 hours, then the exposure is below the CEN daily exposure limit, and the vibration exposure can be considered acceptable. However, if this exposure level were experienced in a European country, it would be necessary for the employer to implement a vibration protection program due to the fact that the exposure exceeds the daily exposure action value.

Section 5: Methods for Reducing Hand-Arm Vibration Hazards

There are many ways to reduce hand-arm vibration hazards:

- buy or use low vibration tools and equipment
- select the lowest vibration tool for the job
- maintain tools and equipment properly
- use tools in ways that minimize vibration exposure
- ensure good ergonomic design of workstations and tasks
- modify tools and equipment to reduce the vibration they produce
- use low vibration work methods
- use gloves and clothing to help maintain blood circulation during work in cold environments
- reduce exposure time and frequency
- train workers
- use anti-vibration gloves

5.1 Buying and Using Low Vibration Tools and Equipment

5.1.1 Identify and Replace Older Higher Vibration Hand Tools

Newer hand-held tools and hand-guided equipment tend to produce less vibration than older units. So replacing older tools and equipment with newer ones can achieve significant reductions in vibration exposure.

5.1.2 Select Tools and Equipment with Built-in Anti-Vibration Features

Many tools have damping or isolation features to reduce vibration. In "damping", a material that absorbs the vibration energy is added to a vibrating component or surface. "Isolation" blocks the transmission of vibration along its travel pathway by introducing a material that is a poor transmitter of vibration. Both techniques are effective at reducing the amount of vibration transmitted to the hands.

5.1.3 Centre of Gravity of Hand-Held Rotational Power Tools

Hand-held rotational power tools have spinning motors or drive shafts in the same axis as the hand and forearm during use (e.g. a power drill) (see Figure 8).

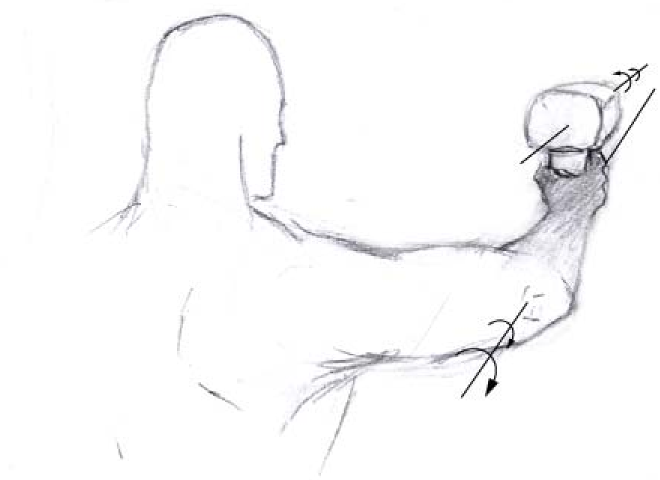

Figure 8: Spinning Axis of Hand-Held Rotational Power Tools

Rotational power tools exert torque (rotational force) against the hand and the user involuntarily counteracts this by tightening the wrist and arm (see Figure 9). Without this counteracting torque by the user, the tool would twist the user's hand and arm along its axis. Application of torque by the tool user makes the effects of vibration exposure worse.

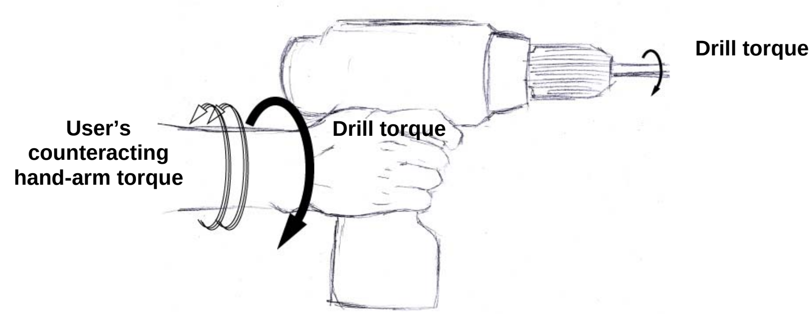

Figure 9: Torque Forces Associated with Rotational Tools

The amount of torque exerted by the tool, and conversely, the amount of torque that the wrist and arm must exert to counteract the tool, can be reduced by choosing tools with a centre of gravity located close to, or just below the hand (see Figure 10).

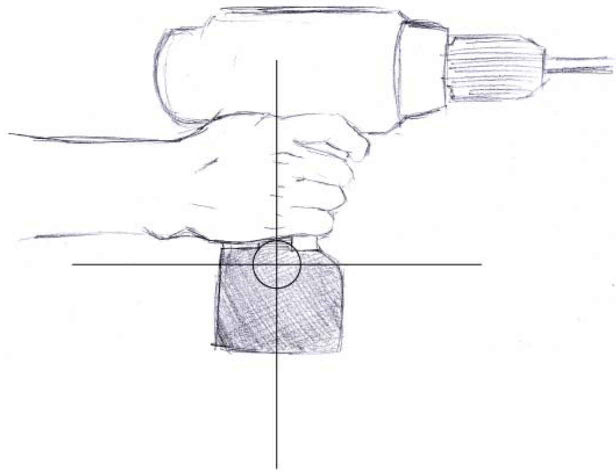

Figure 10: Tool Centre of Gravity

5.2 Selecting the Lowest Vibration Tool for the Job

The tool must be matched to the job in terms of tool size and power. Workers must use a lot of strength when tools are large and have substantial power. This can result in tightened muscles, tendons and ligaments, and easier transmission of hand-arm vibration. If the tool is too small or underpowered, the task may take too long to complete. This can expose the user to vibration for longer than would otherwise be needed.

5.3 Maintaining Tools Properly

Inadequate maintenance can cause parts to become loose, misaligned, worn and unbalanced. This can result in increased vibration output. In addition, blunt, dull and worn cutting edges increase the time needed to complete the job. This results in more exposure to vibration. A maintenance program for vibration reduction should include:

- replacing worn parts,
- replacing defective vibration dampers, mounts, bearings and gears
- sharpening, lubricating and tuning tools
- tuning engines
- replacing anti-vibration mounts and suspended handles
- carrying out necessary balance checks and corrections
- replacing anti-vibration mounts and suspended handles before they deteriorate
- checking the manufacturer's specifications and requirements for maintenance.

5.4 Use Tools in Ways to Reduce Potential Vibration Exposure

5.4.1 Maintain a Proper Grip

The type of grip and tightness used to hold a vibrating tool can affect user posture, and the forces applied against the hand, wrist and forearm. Excessive hand grip force increases ligament and tendon tension and reduces local blood circulation worsening the effects of vibration exposure.

> ***Ligament**s are fibrous connective tissues linking together two or more bones.*
>
> ***Tendons** are fibrous connective tissues linking together bones and muscles.*

When a person is at rest, the ligaments and tendons are relatively "loose" and flexible (think of a loose elastic band). Under these conditions, the ligaments and tendons act as "isolators", reducing the transmission of vibration from bone-to-bone and bone-to-muscle. However, when muscles are tensed they contract and tendons and ligaments are pulled and tightened. Under these tightened conditions, the ligaments and tendons no longer act as "isolators". Instead they more readily transmit vibration from bone-to-bone and bone-to-muscle.

When gripping a vibrating tool, the act of gripping tightens ligaments and tendons in the hand and arm. This assists the transmission of vibration through the hand and to the arm.

> *A **power grip** (power grasp) is a manner of holding an object whereby the fingers are wrapped around the object and the thumb is placed against it – like making a fist.*

Vibration grip-effects can be minimized by:

- using a "**power grip**", which allows the hand to generate the most force while creating the least amount of strain (see Figure 11)
- selecting tools with a centre of gravity located close to, or just below the hand
- using devices such as jigs and suspension systems to reduce the need to grip heavy tools tightly
- using tension chains or elastic leashes above work areas to support vibrating tools such as heavy drills, grinders, nut runners, nailing guns (in some cases) and pneumatic chisels, relieving the operator from supporting the tool's weight
- changing the texture and material of a grip surface to allow the operator to use a smaller grip force to hold and control the tool
- using techniques such as bench-felling in forestry, where the chainsaw slides along the log during de-branching, rather than holding the full weight of the saw at all times (see Figure 12)

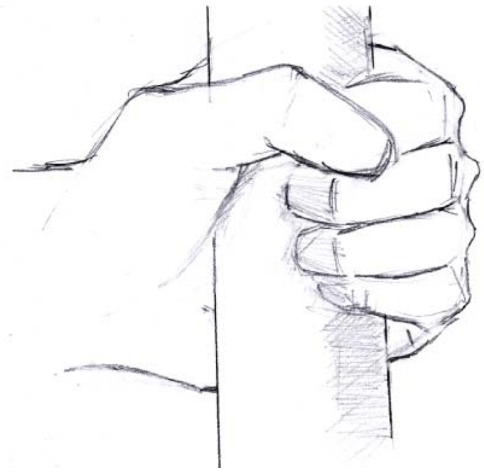

Figure 11: Power Grip

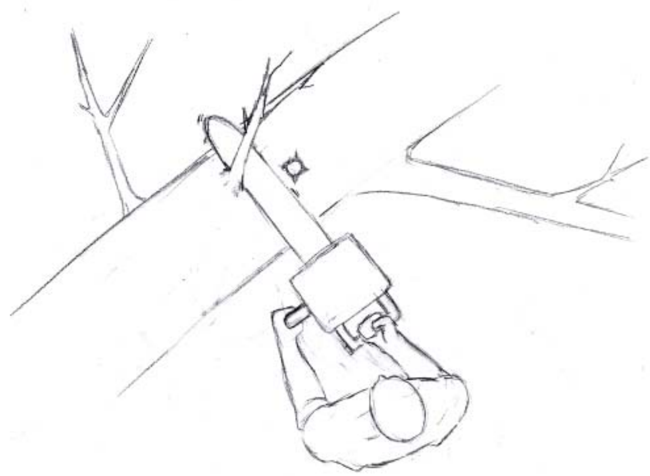

Figure 12: Bench Felling

5.4.2 Proper Hand-Hold Technique

Vibration exposure can be lowered by reducing hand contact with the tool. One way to do this is to rest the tool to the greatest extent possible on the material being worked (or in the case of hand-held work pieces, on the support provided). Of course sufficient hand contact must be maintained for safety.

With some tools, the operator's hands must be in the correct position to avoid more vibration exposure. For example, many vibration-reduced tools, such as jackhammers with suspended handles, produce high vibration emissions if the operator pushes down too hard while operating the tool.

5.4.3 "Hands-Off" and "Shut Off" at the Right Time

To reduce vibration exposure, tools should be operated only when necessary and at the minimum speed and impact force required to perform the work. For example,

- jackhammers should be stopped when lifting them to change position, because many have higher vibration output when pulling up on the handles
- don't needlessly rev chain saws
- don't oversand or overgrind.

5.4.4 Use Sharpness Over Percussion

Percussive drills (hammer drills) with tungsten bits are often used for drilling and boring into concrete or rock. Often, an ordinary non-percussive drill with a diamond bit will do the job as well and as fast, with much less vibration exposure.

5.5 Basic Good Ergonomic Design of Workstations and Tasks

Workstations and tasks should be designed in accordance with good ergonomic principles to minimize loads on workers' hands, wrists and arms, and to promote good posture.

5.6 Modifications to Tools and Equipment

5.6.1 Options for Reducing Vibration and a Cautionary Note

Many types of modifications to tools and equipment can reduce vibration output. These include:

- increasing the mass of the vibrating body
- minimizing tolerances of systems
- balancing machines better
- installing vibration isolators (typically on handles, or where handles connect to the body of the tool)
- installing vibration dampeners.

In practice, many of these modifications are best done when the tool is manufactured, through changes in design and fabrication. Vibration-reducing modifications can be difficult to retrofit. Without adequate technical understanding of how to make improvements, vibration can be increased and the tool or equipment can be made less safe or less ergonomic. Use of unsuitable dampening or isolation materials, or incorrect adjustments to the mass of the vibrating body, can generate resonances that amplify the vibration output at certain frequencies.

5.6.2 Modifications to Handles

There are success stories, involving modifications to tool and equipment handles to reduce vibration transmission:

- De Souza & Moore (1993), conducted a study on the use of a cushioned handle for jackleg rock drills. They found it reduced vibration frequencies reaching the hand by a factor of three. The cushion was made from an elastomer handle which was compared to a steel handle.
- Tudor (1996) developed an ergonomic handle for a string trimmer that would be more comfortable for the operator to use. The handle was slightly curved with a foam surface and reduced vibration.
- Strydom (2000) developed an attenuating rock-drill handle design. This design uses a diaphragm-type absorber that incorporates fluid inertia principles. This design is easily implemented in rock drills, and is relatively simple and inexpensive. It has shown that the transmissibility of vibration can be reduced by 20-40%, compared to unattenuated rock-drill handle transmissibility. The design can be altered for specific drill types and operating frequencies.

5.6.3 Tool Handle Wraps

Many commercially-available viscoelastic materials have been tested as "tool handle wraps". This is similar to wrapping the handle of a hockey stick or tennis racket with tape. The idea is to achieve sufficient thickness to provide some degree of vibration isolation. However, these wraps usually provide insignificant vibration reduction, and can enlarge the tool handle diameter to the point where grip is compromised. There is no evidence that tool wraps are effective in reducing vibration exposure or the risk of hand-arm vibration syndrome.

5.7 Use of Low Vibration Work Methods

It is often possible to change the work method in a way that significantly reduces or eliminates vibration exposure. Table 9 identifies some possibilities.

Table 9: Examples of Work Method Changes to Reduce Vibration Exposure	
Vibration Source	**Alternative Low Vibration Work Method**
Jackhammer for road breaking	Mount a jackhammer onto the boom of a tractor / backhoe
Jackhammer for removal of deteriorating concrete	Water jet blasting
Jackhammer for breaking up concrete foundations and footings	Pilot hole driller on tractor / backhoe, followed by hydraulic bursting
Needle scaling on metal	Grit blasting with vacuum extraction shroud
Needle scaling on exposed face of newly poured concrete	Water jet or grit blasting
Riveting	Bolting, adhesives, or welding
Percussive drilling	Non-percussive drilling with diamond drill bit

Several case studies involving vibration-reducing work methods are presented at the end of this Section.

5.8 Use of Protective Clothing and Gloves to Maintain Blood Flow

Good blood circulation to the fingers and hands may reduce the risk or slow the onset of vibration white finger. It can also reduce the symptoms in cases where vibration white finger has already occurred. To maintain good blood circulation to the fingers and hands, the hands and arms must be kept warm, and a warm body temperature must be maintained.

Consider the following measures to promote blood flow to fingers, hands and arms:

- avoid working outdoors in cold weather, if possible
- use machines with heated handles where available
- maintain the temperature at 16ºC or higher in an indoor workplace
- avoid machines that might make the hands cold, such as steel-bodied machines or pneumatic tools that blow exhaust air over the operator's hands
- for work outdoors, wear cold weather gloves and clothing to keep the worker warm
- use portable hand warmers or battery-powered electrically heated hand gear
- allow workers to warm up before starting work and during work, as needed
- provide an outdoor shelter to allow workers to warm-up, if necessary
- before starting the job, workers should warm their hands
- keep tools in warm storage
- plan work to avoid prolonged exposure to vibration and encourage workers to take breaks during long tasks, as several shorter exposures with 'recovery' periods are preferable to one long exposure

- provide hot drinks and warm food. This helps to maintain body temperature and is particularly important in cold working environments.
- encourage workers to take regular exercise to help circulation and to exercise and massage the fingers during breaks from work with vibrating equipment
- encourage workers to stop or cut down smoking, which can impair circulation.

5.9 Reduce Exposure Duration and Frequency

When engineering controls cannot reduce vibration exposure enough, exposure duration and frequency must be reduced. In many cases, pursuing this option as a first choice may be the most practical approach.

5.9.1 Work Schedules

Where possible, plan and schedule work to prevent workers from being exposed to vibration for long, continuous periods. The specific length of time that a worker can be exposed to the vibration will depend on the vibration level given off from the particular tool. The tool vibration level can be used along with published occupational health and safety laws, standards and guidelines to determine whether exposures are too long. Several shorter periods of exposure are preferable.

5.9.2 Staff Rotation

Where high vibration tools must be used frequently or continuously, rotate tool use and tasks among workers so that no single worker has too long an exposure.

5.10 Instruction and Training

Workers using vibrating hand-held tools must receive instruction and training in the hazards of vibration, how to minimize vibration exposure and how to recognize early signs of overexposure. Specific subjects should include:

- injury / illness risks from use of vibrating tools and equipment
- exposure limit values, guidelines and the exposure action values
- vibration levels associated with the tools and equipment that will be used
- control measures to eliminate or reduce hand-arm vibration, including
    - work practices and ergonomics
    - tool handling techniques - gripping, pushing and guiding
    - maintenance and upkeep requirements and relationship to vibration levels

    - minimizing tool use duration
- early signs and symptoms of injury
- reporting maintenance requirements for tools and equipment
- appropriate health surveillance
- importance of keeping warm
- impact of home activities and lifestyle factors on risks of vibration injury

5.11 Hand-Arm Vibration Reduction Case Studies

5.11.1 Tool Maintenance

Vibration Exposure from Circular Knives and Rotary Tools

Johnson and Wasserman (2000) studied the relationship between hand-arm vibration exposure and the condition of table-mounted circular knives (essentially circular saws) used for meat cutting. They found that use of this equipment did not result in hand-arm vibration overexposure, but vibration levels were higher when the knives had at least one part that was severely worn or damaged. Vibration decreased an average of 16% when the worn parts were replaced. Proper maintenance was shown to be instrumental in minimizing vibration exposure. More broadly, whenever a machine has a symmetrical rotating part (e.g. circular saw blade, drive shaft, gears, flywheels, etc.), that part will emit more significant amounts of vibration when the part becomes asymmetrical due to wear or damage.

Vibration Attenuation Effects from Rock Drill Elastomeric Handles

De Souza and Moore (1993) looked at the long-term effectiveness of elastomer-cushioning placed over the handles of pneumatic jack-leg rock drills used for underground mining. They found that overall hand-arm vibration exposure levels were reduced three-fold.

5.11.2 Training on Proper Tool Use

Effects of Training on Jackhammer Vibration

Macdonald Air Tools Ltd in England studied the effects of jackhammer operator technique on hand-arm vibration. They found that exposures depended on how the tools were used. For example, when breaking concrete, untrained operators were lifting the tool without switching it off (and so increasing the vibration), and were operating continuously for about a minute without moving the cutting tool. The average vibration level was about 9 m/s^2. This meant that the UK exposure action value was reached after about 35 minutes trigger time, and the exposure limit value was reached after about 135 minutes trigger time.

The company produced training material for its customers, which included the following points:

- selecting the correct cutting tool for the job and keeping it sharp
- keeping the handles in the horizontal position for lowest vibration
- letting the weight of the tool do the work
- not gripping the tool too tightly
- moving the cutting tool every 8-10 seconds (since the amount of concrete broken is about the same after 10 seconds as after one minute)
- stopping the tool when lifting it to change position, because the vibration is high when pulling up on the handles
- when cutting concrete, taking small 'bites' to prevent the cutting tool jamming
- removing concrete in shallow layers.

By training the operators to stop the machine before moving it, the average vibration level was reduced to around 7 m/s^2, allowing a 70% increase in the time before the exposure action and limit values were reached. Further training improved the operators' techniques and the average vibration was reduced to about 5.5 m/s^2, allowing about 100 minutes trigger time before reaching the exposure action value. By training the operator to stop and move the cutting tool after about 10 seconds of operating, instead of working continuously for about a minute, the amount of work done (concrete broken) was greatly increased. The overall effect was to allow up to 17 times more concrete to be broken than before, without increasing vibration exposures.

User Technique Affects Hand-Arm Vibration Exposure

Edwards *et al*. (2006) monitored hand-arm vibration exposures from three different types of tools - electric breakers, combi-hammers and battery drills – made by three different manufacturers. Several operators used each tool to work on a single point of a piece of concrete for 30 seconds, while vibration was measured. There was a significant difference observed between the vibration levels of the tools when the same tool was used by each of the three operators, indicating that the individual's method of use has a significant effect on hand-arm vibration exposure.

5.11.3 Use of Low Vibration Work Methods

Methods for Reducing Manual Jackhammering

Manual use of pneumatic jackhammers produces hand-arm vibration levels in the range of 5 to 20 m/s^2 with an average of around 12 m/s^2. At the average vibration level, a total of 3 hours use per day which would give a typical exposure of 7 m/s^2, which is more than the maximum exposure limits recommended by ACGIH® and the European Vibration Directive. There are ways in which vibration from manual jackhammering can be reduced or eliminated by alternative methods.

Use Tractor Mounted Jackhammers

Human vibration exposure caused by jackhammering can be greatly reduced by mounting the jackhammer onto the articulating arm of a tractor or excavator, using the machine's hydraulics to power the jackhammer, and operating it from the driver's station. This approach can drop the jackhammer's contribution to hand-arm vibration down to less than 1 m/s^2. If finer work is required, such as scoring the border of an area to be broken out, this work can be done with a hand-held jackhammer. In this case the total amount of hand-held time is still very short (often minutes), still resulting in acceptably low exposures. An added benefit of using a machine-mounted jackhammer is that the work usually proceeds many times faster than by hand-held jackhammering.

Use Directional Drilling or Daylighting Instead of Excavation

When laying wire or pipe under roads or walkways, one method is to excavate a trench and lay the wire or pipe. Jackhammers are often used to break the surface and manual tampers are often used as part of the backfilling and restoration work. One way of avoiding vibration from jackhammer and tamper operation is to use directional drilling or daylighting to create the underground pipe or wire chase instead of opening a trench. In addition to virtually eliminating hand-arm vibration exposure, these methods are often cheaper than trenching, generally much faster and less disruptive.

Use a "Drill and Bite" Technique to Tear Down Concrete Walls

Concrete walls are often broken down by jackhammering. As an alternative, a diamond drill held in a clamp can be used to drill a series of holes through the wall, after which a hydraulic concrete crusher can be used to "bite off" pieces. The jaws of hydraulic crushers close slowly, so operators can loosen their grip before crushing takes place, further reducing vibration exposure. This technique results in negligible operator exposure to hand-arm vibration and also significantly reduces noise and dust exposures.

Using Hydraulic Bursting for Concrete Demolition

Jackhammers are often used to break-up concrete slabs and footings. As an alternative, a clamp-mounted diamond drill can be used to drill holes in the concrete, after which a hydraulic bursting tool can be inserted into the holes to split apart the concrete. This method produces very little exposure to vibration, noise and dust.

Removal of Large Sections of Brick or Concrete Structures to Modify Buildings

In commercial and industrial buildings, very large openings through thick (1m+) concrete or brick slabs and walls to route services, install elevator shafts, install escalators, etc. must sometimes be done. A typical technique is to use lower force hand-held jackhammers to cut out the entire mass of material, since larger jackhammers or machine-mounted jackhammers can produce too much vibration which can cause structural damage to the building. An alternative lower vibration approach is to cut a border around and completely through the material to be removed with a diamond core or wire saw, which essentially “vibration isolates” the target material from the building, and then use a tractor mounted jackhammer to breakout the isolated section. In addition to resulting in less vibration, this method can be much quicker.

Water Jets to Remove Damaged or Weathered Concrete Surfaces

Instead of using hand-held jackhammers to remove damaged, weathered and decayed concrete material from buildings or bridges, a robot-mounted water jetting machine can be used. This process uses an extremely high pressure water jet to wear away the old damaged concrete. The jet removes all concrete up to a certain strength, regardless of depth, leaving the good material and removing the damaged material. As a result, operators are not exposed to hand-arm vibration, and airborne dust levels are very low.

Methods for Reducing Needle Gun Use

For Surface Preparation, Try Grit Blasting Instead

For many situations where needle guns are used – e.g. removing rust or scale from metal surfaces, roughing-up concrete surfaces to facilitate bonding – grit blasters with local exhaust ventilation shrouds can be used instead.

Using Concrete Curing Retarders to Create a Rough Bonding Surface

Needle guns are sometimes used to rough-up bonding surfaces of newly poured concrete after removal of forms. As an alternative, the surface to which the next pour will be bonded can be coated with a concrete cure retarding compound. Then, when the bulk of the concrete has cured, the surface to which the retarding compound has been applied will still be largely uncured. Then, when forms are removed, the uncured surface can be abraded with a pressure washer to create a rough bonding surface.

5.12 Use of Anti-Vibration Gloves

Many conventional gloves dampen higher frequencies of vibration present in some tools. However, it is more difficult to get conventional gloves to dampen and reduce the lower vibration frequencies present in many tools such as pneumatic chipping hammers and jackhammers.

Anti-vibration gloves have been available and in use since the early 1980s. The most basic types of anti-vibration gloves have outer skins made of conventional materials (e.g. leather), and an inner liner made of one or more viscoelastic materials intended to dampen vibration. Some inner liners combine two or more layers of different viscoelastic materials, or have air pockets sandwiched between viscoelastic layers.

The first standard for testing anti-vibration glove efficiency was published by the American National Standards Institute in 1988 (ANSI S3.40), and in 1997 the International Organization for Standardization published ISO 10819, which is now the most commonly cited anti-vibration glove test standard.

Anti-vibration gloves that meet ISO 10819 may confer vibration reducing benefits for workers exposed to mainly high frequency hand-arm vibration (such as from very high speed rotational tools), and several studies have reported some user benefits in terms of reduced high frequency vibration exposure, and mild reduction in the severity of hand-arm vibration symptoms.

However, compliance with the ISO 10819 standard does not show that a glove provides reduction in the lower frequency range; and tests show that most anti-vibration gloves do not provide significant risk reduction at frequencies below 150Hz. Since the vibration emissions of most powered hand tools are below 150 Hz, the reduction in vibration provided by anti-vibration gloves is negligible in most cases.

If anti-vibration gloves are to be used to protect against high frequency vibration, the gloves should:

- not compromise grip strength
- allow the worker to maintain a sense of touch
- adequately insulate to protect against cold
- have a relatively thin vibration-damping material that is flexible
- have vibration damping material that covers the full palm area, fingers and thumb
- have an opposed thumb
- be loose fitting
- allow the necessary dexterity to complete a task
- allow freedom of movement to control the tool.
- adequately protect against other hazards (e.g. cuts, abrasions)
- meet the anti-vibration glove standard ISO 10819.

Section 6: Methods for Reducing Whole Body Vibration Hazards

There are many ways to reduce whole body vibration hazards:

- purchasing practices
- reducing exposure time and frequency
- providing training and instruction
- implementing suspension systems in vibrating equipment
- modifying seating
- maintaining driving surfaces
- modifying driving practices
- maintaining tires and wheels
- changing the cab design
- maintaining the engine
- providing remote operation of equipment
- damping or isolating the vibration source or surface

6.1 General Methods

6.1.1 Purchasing Practices

When purchasing equipment,

- determine whether the manufacturer / supplier has data relating to whole body vibration exposure under a range of operating conditions
- specify to the manufacturer / supplier what the maximum whole body vibration exposures must be under typical operating conditions
- determine what vibration reduction systems are in place, and their maintenance requirements
- determine what components of the equipment contribute most significantly to vibration output, and how to maintain those components to minimize vibration.

6.1.2 Reduce Exposure Duration and Frequency

When engineering control measures cannot adequately reduce vibration exposure, exposure duration and frequency must be reduced. In many cases, pursuing this option as a first choice may be the most practical approach.

Where possible, plan and schedule work to prevent workers from being exposed to vibration for long, continuous periods. Several shorter periods of exposure are preferable.

Where it is necessary to continually operate high vibration equipment, rotate operation among workers so that no single worker has exposures long enough to become overexposed. This could be done by switching operators between higher and lower vibration equipment.

Operators of equipment should also take periodic rest breaks of 10 to 15 minutes for every 1 to 2 hours of continuous exposure.

6.1.3 Training and Instruction

Workers operating equipment that results in whole body vibration exposure must receive instruction and training in the hazards of vibration, how to minimize vibration exposure and how to recognize early signs of overexposure. Specific subjects for coverage should include:

- injury / illness risks from exposure to whole body vibration
- exposure limit values, guidelines and the exposure action values
- vibration levels associated with equipment that will be used
- control measures to reduce risks from vibration exposure, including
    - equipment maintenance and upkeep requirements and relationship to vibration levels
    - minimizing exposure duration
    - proper sitting and posture
    - how to adjust seats for optimal seating position and posture
    - driving and routing practices to reduce vibration
    - need to avoid lifting or bending immediately following exposure, and to avoid twisting or body rotation during equipment operation.
- early signs and symptoms of injury
- reporting maintenance requirements for equipment
- appropriate health surveillance
- impact of home activities and lifestyle factors on risks of vibration injury.

6.2 Specific Methods for Reducing Whole Body Vibration Exposure from Vehicles

6.2.1 Suspension Systems (Chassis and / or Cab)

Suspension systems must be regularly maintained, and maintenance personnel must be able to recognize and remedy conditions that increase vibration exposure.

The suspension system components (springs, shocks, etc.) must be designed for the mass of loads typically carried by the vehicle. Overloading and underloading can both increase whole body vibration exposure. Ideally, suspension systems should be "smart" and self-adjusting to achieve optimal vibration reduction for a range of load conditions. Where possible, avoid the purchase and use of unsprung vehicles.

If the suspension system must be modified to meet job conditions, ensure that modifications are designed and implemented by personnel with expertise in vibration reduction. Improperly sized, configured and tuned systems can amplify rather than reduce vibration.

6.2.2 Seating

Most conventional vehicle seats resonate vertically (z-axis) at around 4 Hz. As a result, they amplify vibration at these frequencies. This is important because the human body is most sensitive to vibration in the range 4-8 Hz in the z-axis. Seats can also amplify vibration in the x-axis (front to back) and the y-axis (side to side). When seats are mounted sideways ("troop carrier" style), the x-axis vibration moves the spine from side to side, which can cause injury. Vibration in the x and y-axes can also be significant for vehicles operating on uneven terrain. When seats are not maintained or replaced on a regular basis, they can add to vibration problems because seat suspension systems deteriorate over time.

Seats can suffer from a variety of deficiencies that magnify the effects of vibration exposure:

- many lack adequate back support
- lack of visibility or the need to twist around to see backwards may limit the benefits of a good seat
- many are not maintained to the manufacturers' design specifications and are not replaced regularly enough
- many are not designed and installed to minimize vibration transmission to the operator
- many actually amplify vibration frequencies and increase exposure.

Good seating-related practices for vibration reduction include:

- equipping vehicles with air-ride seats or seats with suspension systems
- using ergonomically designed seats and back rests, with adequate padding
- providing seatbelts and supports for the lower back
- training operators to properly adjust the seat.

Seats should be designed to reduce the transmission of vibration to the lowest possible level. Seat suspension systems can amplify vibrations of certain frequencies, and many have been found ineffective in reducing overall vibration exposure. It is therefore important to get professional assistance when retrofitting vehicles with seat suspension systems. The seat should be selected so that the dominant frequency of the vehicle's vibration is not in the amplification range of the suspension system.

Additional considerations when selecting a suspension seat include:

- having sufficient space to allow the workers to move
- adjustability in various directions (height, fore-aft, backrest)
- ease of access to adjustment controls, with height adjustments separate from suspension adjustments
- ability to adjust the seat in accordance with the operator's weight
- sufficient cab space for fore and aft adjustment.

6.2.3 Driving Surfaces

Poor roads, uneven work areas and off-road terrain contribute significantly to rough rides, jarring and vibration exposure.

Practices to minimize the vibration exposure contribution of driving surfaces include:

- properly maintaining roads and driving surfaces, if possible
- using the right type of vehicle, suspension system and tires for the surface conditions
- equipping vehicles with headlights so that drivers can see and judge surface conditions
- instructing drivers in driving techniques to minimize surface vibration effects
- ensuring that the vehicle cab and windows are designed and maintained so that the driver can see road surface conditions a few metres in front of the vehicle
- getting feedback from workers on problems and conditions contributing to rough rides
- encouraging operators to communicate among themselves on road and surface conditions
- using markers and signage for particularly rough areas

6.2.4 Driving Practices

Driving practices can have a large effect on whole body vibration exposure. Exposure reducing practices include:

- choosing a driving speed for the terrain that minimizes vibration of the vehicle (slower speeds typically result in less vibration)
- avoiding potholes, ruts, and bumps
- avoiding long periods of driving without leaving the vehicle to stretch and have a break
- providing drivers with feedback on the effectiveness of their driving style for reduction of vibration exposure
- training.

6.2.5 Tires and Wheels

Over inflated tires produce a rougher ride while under inflated tires can produce a bouncier ride. Ensure tires are correctly inflated for the particular type of vehicle and road conditions.

Unevenly worn tires (e.g. more worn on the front than back) can also increase vibration, so periodic inspection for tire wear and tire rotation are important.

Maintaining proper wheel alignment is also important for reducing vibration.

6.2.6 Cab

Vehicle cabs can be designed and installed to be mechanically isolated from the chassis and engine. This significantly reduces vibration transmission to the operator. Vibration-isolated cabs must be inspected periodically and isolation system components must be properly maintained.

For cabs that are not or cannot be vibration isolated, insulating or damping the floor with anti-vibration materials can sometimes have some vibration reducing benefit, but mainly for higher frequencies.

Incorporating good ergonomic design principles into cab design and layout can minimize the impacts of whole body vibration by avoiding the need for the operator to adopt bad postures or engage in undesirable motions. Cabs should:

- minimize the need for the operator to twist the body or neck, or strain the neck upward to see over obstacles

- provide adequate head, leg and body room, so that the operator is not cramped and can easily operate the controls
- allow adequate visibility of the path of operation
- have high visibility displays and controls
- be provided with swivel seats if it is necessary for the operator to change directional orientation of their body to operate attachments such as backhoes.

6.2.7 Engine Maintenance

Engines can be sources of both high and low frequency vibration. To minimize the contribution of the engine to overall vibration exposure, it is important to maintain the engine regularly. This way conditions that can increase exposure, such as worn parts, defective vibration dampers, bearings and gears, and engine tuning can be identified and fixed.

6.2.8 Remote Operation

For certain vehicles and situations, operator vibration exposure can be eliminated by designing and equipping the vehicle for remote operation. This has been done successfully with vehicles used for drilling and digging, load-haul-dump vehicles ("LHD") used in mining, and railway locomotives. In some applications (like tracked drillers), the operator walks beside the machine while it is moving and stands beside the machine during stationary work. It is also possible to provide the operator with a second vehicle (such as an all terrain vehicle or truck) for shelter and lower vibration personal transport. In other applications, like mine LHD and railways, the operator controls the vehicle from a permanent workstation remote from the worksite.

6.3 Specific Methods for Reducing Whole Body Vibration Exposure from Stationary Machinery

6.3.1 Conventional Vibration Isolation and Damping

The usual way that vibration is reduced for stationary equipment on a mounting platform or the floor of a building is to position the equipment on pads made of rubber bonded cork or similar materials. Therefore the equipment is not in direct physical contact with the platform or building. The pads are made of materials that are poor transmitters of vibration.

If an operator must stand or sit on a platform that is attached to the stationary equipment, then this platform, or the structural members that secure it to the equipment, can be separated from direct contact with the vibration-producing stationary equipment by installing vibration-isolating pads.

Figure 13 illustrates how vibration-isolating pads are typically installed.

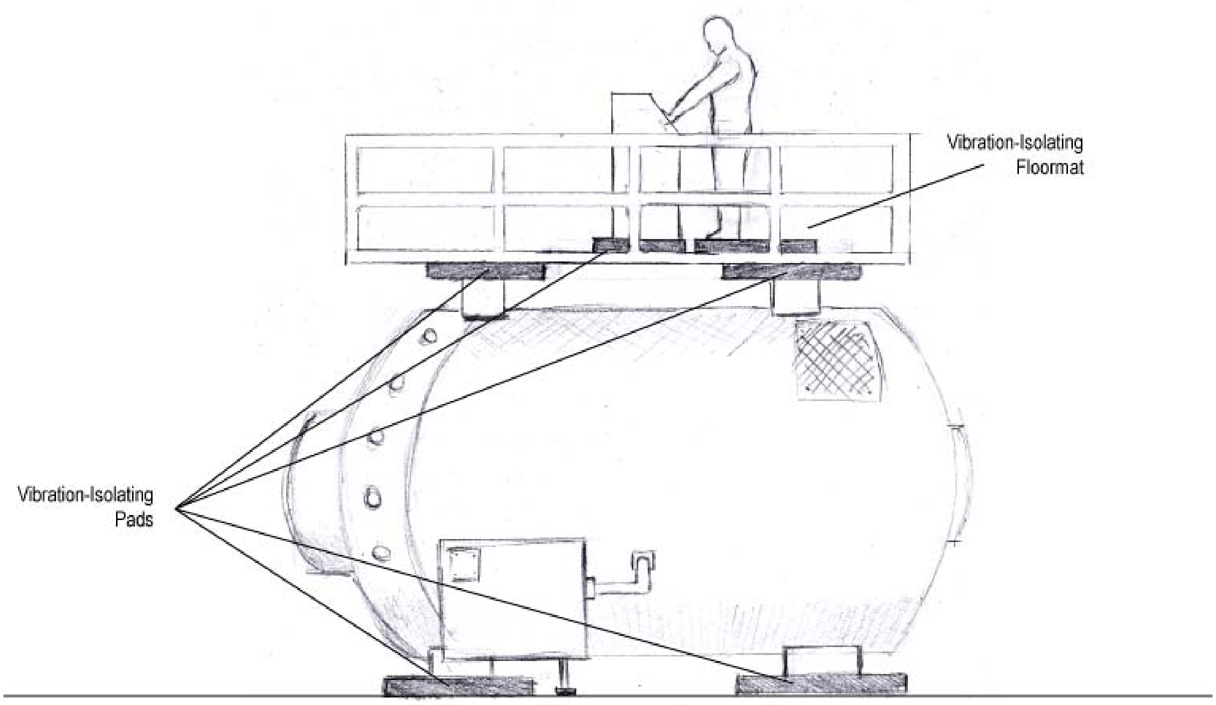

Figure 13 - Typical Installation of Vibration-Isolating Pads

Since noise is created by vibrating surfaces, the use of vibration-isolating pads also usually reduces noise levels.

When installing vibration-isolating pads, it is essential that either there be no penetrations through the pad (such as bolts) which provide a new alternative path for transmission of vibration, or additional vibration-isolators are installed in the manner of washers to isolate the bolts and fasteners.

The correct type and size of isolator is determined by the mass of the stationary equipment and the frequency of vibration to be isolated. Specialists in vibration-isolation should be consulted on proper treatments.

6.3.2 Seating

The information provided for vehicle seating in Section 8.2.2 also applies to seating installed as part of a control station for stationary equipment.

6.3.3 Standing Surfaces

As shown in Figure 13, standing surfaces can be vibration-isolated from vibrating components by installing vibration-isolating pads.

Anti-fatigue mats placed on the standing or walking surfaces of platforms can reduce higher frequency vibration, primarily by dampening vibration transmitted along the surface. However, these mats are not very effective at reducing vibration transmission in the potentially harmful 4 to 8 Hz range.

6.3.4 Maintenance

The information provided for vehicle maintenance in Section 8.2.7 applies equally to the maintenance of stationary equipment.

6.4 Case Studies

Impacts of an Education Program on Forklift Driver Whole Body Vibration Exposure

A study by Hulshof *et al*. (2006) monitored the effect of administering an educational program to 180 forklift drivers in Holland. The program included information on major causes of high exposure to whole body vibration and guidance on safe behaviour when operating forklifts. It urged drivers to reduce their speed and adopt a calm driving style. Each of the participants was monitored when operating a forklift to determine the level of vibration to which they were exposed. The intervention resulted in an overall 10% reduction in average exposure to whole body vibration.

Multifacted Approach to Reducing Lower Back Pain in Forklift Drivers

A study by Shinozaki *et al*. (2001) assessed the effectiveness of a two stage approach for reducing lower back pain in a group of 260 forklift operators. In the first stage, lumbar supports were provided and a physical exercise program was implemented. One year after implementation, the prevalence of lower back pain fell from 63% to 56%. Improvements were then made to forklift seats and tires. Nine months after these changes were made, the prevalence further decreased to 33%.

Section 7: OHS Laws, Guidelines and Standards Related to Vibration

7.1 OHS Laws Related to Vibration

This section explains the extent to which Canadian and selected international jurisdictions address vibration exposure hazards and control measures in their occupational health and safety (OHS) laws.

7.1.1 Alberta OHS Laws

Alberta's *Occupational Health and Safety* (OHS) *Act*, OHS Regulation, and OHS Code do not contain provisions specific to the control of exposure to vibration. However, Section 2 of the *OHS Act* establishes a general duty for employers to protect the health and safety of workers from workplace hazards:

> *Every employer shall ensure … the health and safety of workers engaged in the work of that employer.*

Part 2 of the OHS Code requires an employer to assess hazards at the work site. If a hazard (or potential hazard) to workers is identified, workers must be protected.

7.1.2 British Columbia OHS Laws

British Columbia is unique among Canadian jurisdictions since it has set specific standards for worker protection from vibration. British Columbia has adopted by reference the maximum permissible vibration exposure limits set out in ACGIH and ANSI/CEN Standards for hand-arm vibration and whole body vibration, respectively.

7.1.3 Canadian Federal OHS Laws

The *Canada Labour Code Part II* and regulations provide occupational health and safety rules for federal government workplaces, federal undertakings, and workplaces of federally regulated employers. In clause 125(1)(n), the *Canada Labour Code Part II* establishes a duty for employers to

> *…ensure that the levels of ventilation, lighting, temperature, humidity, sound and vibration are in accordance with prescribed standards (125(1)(n)).*

The only "prescribed standards" referenced in clause 125(1)(n) are those in section 14.10 of the *Canadian Occupational Health and Safety Regulations*, which states:

> *…an employer shall ensure that all motorized materials handling equipment in use is designed and constructed so that any employee required to operate or ride on it will not be injured or its control will not be impaired by any vibration, jolting or uneven movement of the materials handling equipment.*

In summary,

(i) within the federal jurisdiction, occupational health and safety regulatory requirements relating to vibration are those that apply specifically to vibration exposure from operation of mobile material handling equipment and,

(ii) the employer is obliged to ensure that no "employee is injured… by any vibration".

7.1.4 United States OHS Laws

As with Canadian jurisdictions, the United States federal and state occupational health and safety laws establish general duties for employers to protect the health and safety of workers. However, except in California, there are no specific requirements on vibration exposure hazards.

California has enacted the *Regulations on Repetitive Motion Injuries* (Title 8 Regulations, Subchapter 7, Group 15, Article 106, Section 5110). This law requires employers to establish and put in place a program to minimize repetitive motion injuries in cases where such injuries have occurred in the workplace. The regulations do not discriminate among causes of repetitive motion injuries, and so programs are required in cases where injuries are caused by overexposure to hand-arm or whole body vibration. Where a program is required, it must include a worksite evaluation, control of harmful exposure and training for workers.

7.1.5 European Union OHS Laws

European Union Directives set standards that member countries must adopt directly or in country-specific legislation. In 2002, the European Union adopted the *European Vibration Directive (2002/44/EC)*. This Directive sets minimum requirements for the health and safety of workers exposed to vibration. The Directive establishes several requirements for the protection of workers from vibration, including:

- employers must conduct risk assessments for vibration hazards (this requires the employer to measure vibration levels of tools, machinery and equipment that can expose workers to vibration and determine worker exposure)
- limits for maximum permissible vibration exposures

- requirements for employers to reduce worker exposures through control measures
- recommendations for the health surveillance of workers at significant risk of vibration exposure

The legislated maximum permissible vibration exposure limits are:

For hand-arm vibration:

- A daily **exposure limit value** of 5 m/s^2 standardized to an eight-hour reference period.
- A daily **exposure action value** of 2.5 m/s^2 standardized to an eight-hour reference period.

For whole body vibration:

- A daily exposure limit value of 1.15 m/s^2 (or, vibration dose value of 21 $m/s^{1.75}$) standardized to an eight-hour reference period.
- A daily exposure action value of 0.5 m/s^2 (or, vibration dose value of 9.1 $m/s^{1.75}$) standardized to an eight-hour reference period.

7.1.6 United Kingdom OHS Laws

In 2006, the United Kingdom passed *The Control of Vibration at Work Regulations 2005*, based on the *European Vibration Directive (2002/44/EC).* It requires employers to:

- assess vibration exposure risks
- determine if workers are likely to be exposed above the daily exposure action value
- where exposures exceed the daily exposure action value, introduce a program of controls to eliminate or reduce exposures to as low a level as is reasonably practicable
- provide health surveillance to workers who continue to be regularly exposed above the action value or otherwise continue to be at risk
- provide information and training to workers about health risks and actions to control vibration exposure risks
- keep a record of risk assessments, control actions, and health surveillance records for vibration exposed workers
- periodically review and update the risk assessment.

The legislated maximum permissible vibration exposure limits are the same as those specified in the *European Vibration Directive* (see Section 7.1.5).

As a result of this law, a considerable amount of in-depth information on workplace vibration exposure and control methods is available from sources in the United Kingdom.

7.1.7 International Labour Organization

In 1977, the International Labour Organization held the "The Convention Concerning the Protection of Workers against Occupational Hazards in the Working Environment Due to Air Pollution, Noise and Vibration" (ILO No. 148, 1977). This event focused on the protection of workers from vibration. Resolutions of the Convention include the following:

> *National laws or regulations shall prescribe that measures be taken for the prevention and control of, and protection against, occupational hazards in the working environment due to air pollution, noise and vibration. Article 4(1)*
>
> *Provisions concerning the practical implementation of the measures so prescribed may be adopted through technical standards, codes of practice and other appropriate methods. Article 4(2)*
>
> *As far as possible, the working environment shall be kept free from any hazard due to air pollution, noise or vibration. Article 9*

ILO standards are expected to guide public policy in countries that are signatories to specific ILO conventions. Canada has not adopted this ILO standard.

7.2 OHS Guidelines and Standards Related to Vibration

This section provides information about non-regulated and voluntary standards relating to vibration exposure limits, vibration measurement techniques, minimizing vibration through design and fabrication, and vibration control methods.

7.2.1 American Conference of Governmental Industrial Hygienists® Threshold Limit Values®

The American Conference of Governmental Industrial Hygienists (ACGIH®) is a not-for-profit and member-based organization that stimulates workplace and environmental health by providing education and information for professionals on how to apply recommended standards. Allowable workplace exposure limits recommended by ACGIH® are published each year in its booklet titled *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices* ("the TLV® booklet").

The TLV® booklet presents recommended maximum permissible occupational exposure limits for both hand-arm vibration and whole body vibration.

Hand-arm vibration limits are set out in Table 2 of the TLV® booklet. These vibration exposure limits are set with the goal of preventing most workers repeatedly exposed at the stated levels from progressing beyond Stage 1 of the Stockholm Workshop Classification System for Vibration-Induced White Finger.

Whole body vibration exposure limits are determined in accordance with a specified methodology and reference values set out in Table 3 of the TLV® booklet. The exposure limits set mechanically induced whole body vibration levels and durations under which it is thought that most workers may be exposed repeatedly with minimum risk of back pain, adverse health effects to the back, and inability to operate a vehicle properly.

7.2.2 International Organization for Standardization - Whole Body Vibration Exposure Standard

ISO 2631-1, 1997 - Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration -- Part 1: General requirements, is a standard that,

(i) incorporates assessment methods for both steady state and shock type whole body vibration, and
(ii) provides guidance for acceptable workplace vibration exposures.

The standard classifies vibration exposures into three categories or "zones":

- *likely health risk zone*, where vibration exposure is likely to be a risk to health (based on evidence of documented exposure-health effects)
- *caution zone*, where vibration exposure is a potential risk to health
- *below the caution zone*, where the vibration exposure level is considered acceptable and unlikely to be a risk to health.

These zones are not intended to be treated as absolute predictors of risk, but rather as guidance for health risk assessment by professionals.

7.2.3 Hand-Arm Vibration Measurement Standards

Several standards have been developed by the International Organization for Standardization to classify recognized good practices for evaluating hand-arm vibration exposure, and measuring vibration emissions of hand-held tools. These include:

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

- *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.*

- *ISO 8662-1 (1988): Hand-held portable power tools – Measurement of vibrations at the handle, Part 1: General*

- *ISO 8662-3 (1992): Hand-held portable power tools – Measurement of vibrations at the handle, Part 3: Rock drills and rotary hammers*

7.2.4 Other Vibration Standards Published by Non-Regulatory Governmental Agencies and Non-Governmental Standards-Promulgating Organizations

Several non-regulatory governmental standards agencies and non-governmental standards-promulgating organizations have produced standards for vibration exposure assessment, vibration measurement methods, recommended maximum permissible exposure limits, vibration control measures, and design and fabrication criteria for vibration reduction in equipment and vehicles. Several of these standards are listed below.

Canadian Standards Association (CSA)	
Agricultural Wheeled Tractors – Operator's Seat – Laboratory Measurement of Transmitted Vibration	CAN/CSA-M5007-03
Earth-Moving Machinery – Laboratory Evaluation of Operator Seat Vibration	CAN/CSA-M7096-00
Procedure for Measurement of Sound and Vibration Due to Blasting Operations	CAN3-Z107.54-M85 (R2001)

American National Standards Institute (ANSI)	
Guide to the Evaluation of Human Exposure to Vibration in Buildings	ANSI S2.71-1983 (R2003)
Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand	ANSI S2.70-2006
Mechanical Vibration and Shock – Evaluation of human exposure to whole-body vibration	ANSI S2.72-2002 (R2007) / ISO 2631-4-1997 (R2007)

National Institute of Occupational Safety and Health (United States Department of Health and Human Services)	
Criteria for a Recommended Standard: Occupational Exposure to Hand-Arm Vibration	NIOSH 89-106

European Committee for Standardization (European Normalization (CEN))	
Mechanical vibration and shock - Measurement and evaluation of single shocks transmitted from hand-held and hand-guided machines to the hand-arm system	CEN ISO/TS 15694:2004
Hand-held portable power tools - Measurement of vibrations at the handle - Part 11: Fastener driving tools	CEN ISO/TS 8662-11:2004
Whole body vibration - Guidelines for vibration hazards reduction	CEN/TR 15172:2005
Mechanical vibration - Guideline for the assessment of exposure to hand-transmitted vibration using available information including that provided by manufacturers of machinery	CEN/TR 15350:2006
Hand-arm vibration - Guidelines for vibration hazards reduction	CR 1030:1995
Mechanical vibration - Guide to the health effects of vibration on the human body	CR 12349:1996
Mechanical vibration - Testing of mobile machinery in order to determine the vibration emission value	CEN 1032:2003
Mechanical vibration - Declaration and verification of vibration emission values	CEN 12096:1997
Safety of industrial trucks - Test methods for measuring vibration	CEN 13059:2002
Mechanical vibration - Industrial trucks - Laboratory evaluation and specification of operator seat vibration	CEN 13490:2001
Mechanical vibration - Measurement and calculation of occupational exposure to whole body vibration with reference to health - Practical guidance	CEN 14253:2003+A1:2007
Hand-held portable power tools - Measurement of vibrations at the handle	CEN 28662:1992
Mechanical vibration - Laboratory method for evaluating vehicle seat vibration - Part 1: Basic requirements (ISO 10326-1:1992)	CEN 30326-1:1994
Mechanical vibration and shock - Hand-arm vibration - Method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand (ISO 10819:1996)	CEN ISO 10819:1996
Mechanical vibration and shock - Hand-arm vibration - Method for measuring the vibration transmissibility of resilient materials when loaded by the hand-arm system (ISO 13753:1998)	CEN ISO 13753:1998
Mechanical vibration - Hand-held and hand-guided machinery - Principles for evaluation of vibration emission (ISO 20643:2005)	CEN ISO 20643:2005
Earth-moving machinery - Laboratory evaluation of operator seat vibration (ISO 7096:2000)	CEN ISO 7096:2000
Human response to vibration - Measuring instrumentation (ISO 8041:2005)	CEN ISO 8041:2005

International Organization for Standardization (ISO)	
Human response to vibration – Measuring instrumentation	ISO 8041:2005
Earth-moving machinery - Laboratory evaluation of operator seat vibration	ISO 7096:2000
Agricultural wheeled tractors - Operator’s seat - Laboratory measurement of transmitted vibration	ASABE/ISO 5007:2003
Mechanical vibration and shock – Human exposure - Vocabulary	ISO 5805: 1997
Agricultural wheeled tractors and field machinery - Measurement of whole body vibration of the operator	ASABE/ISO 5008:2002
Mechanical vibration and shock – Evaluation of human exposure to whole body vibration	ISO 2631-1-1997 (R2007)

Society of Automotive Engineers (SAE)	
Human Mechanical Response Characteristics, Dynamic Response of the Human Abdomen	SAE J1460/1
Human Tolerance to Impact Conditions as Related to Motor Vehicle Design	SAE J885

Japanese Standards Association (JIS)	
Method of Measurement and Description of Hand-Transmitted Vibration Level	JIS B4900

Australia Standards Association (ASA)	
Vibration and Shock - Hand-transmitted vibration - Guidelines for and measurement and assessment of human exposure	AS 2763-1988
Vibration and Shock - Dynamic characteristics of the human body	AS 2993.1-1987
Evaluation of human exposure to whole body vibration – General requirements	AS 2670.1-2001

Chinese Standards (GB/T)	
Reduced comfort boundary and evaluation criteria for human exposure to whole body vibration	GB/T 13442-1992
Comfort evaluation of human exposure to whole body vibration in recumbent position	GB/T 13442-1992
Vibration and shock - Mechanical transmissibility of the human body in the z direction	GB/T 16441-1996

Deutsches Institut für Normung Standards (DIN) (Holland)	
Hand-held portable power tools; measurement of vibrations at the handle	DIN CEN 28662

Several of the European Committee for Standardization's standards are based on ISO standards, and the standard listed for Holland is a country-specific adoption of the corresponding CEN standard. Also, the ASA standard for evaluation of human exposure to whole body vibration is very similar to the CEN and ISO standards.

Appendix 1

1.0 Principle for Measuring Vibration

Vibration measurement requires the use of an instrument that can convert physical vibration into an electrical signal. The electrical signal is then relayed to a display telling the user how much vibration is coming from a source. The components of a vibration measuring instrument are shown in Figure A1.

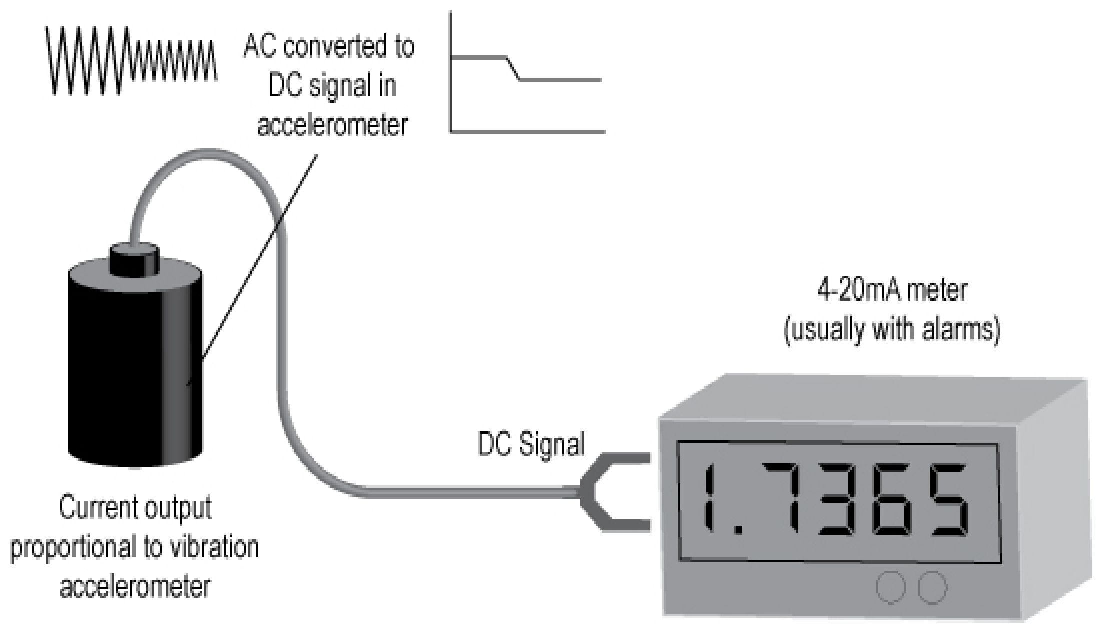

Figure A1 – Components of a Vibration Measurement Instrument
(Adapted from *Accelerometers*, Honeywell, 2007)

The typical arrangement of equipment includes a mechanical transducer attached to a vibrating surface or object, a preamplifier, filters and a display.

The transducer is a microphone used to pick up a vibration signal. There are various types of transducers, including accelerometers, vibrometers, and displacement meters. The most common is the accelerometer. The transducer is placed firmly and securely on the vibrating surface in an area that most closely approximates where the user holds the vibrating tool or sits on the vibrating equipment. Often the transducer needs to be attached to the vibrating surface by some means (e.g. wax, soft glue, magnet) so that it makes good contact with the vibrating surface.

Attached to the transducer is a preamplifier. The preamplifier intensifies the signal that is provided from the transducer. Once amplified, the vibration is converted into an electrical signal. This signal may need to be converted into specific units. In such cases, an integrator / differentiator is used. The integrator is placed between the preamplifier and the filters. It allows vibrations to be measured with an accelerometer or accelerations with a vibrometer.

Since vibration is harmful according to its frequency, the electrical signal then passes through filters where the vibration signal is weighted according to frequency. In simple terms, weighting means that the signal is divided into various frequencies and ranked based on the amount of each frequency present. The weighted vibration levels can then be read from a display attached to the filters.

Measuring Hand-Arm Vibration

In the case of hand-arm vibration, the transducer is affixed to the vibrating surface where the worker holds the tool. The vibration that would normally be transmitted to the worker's hand and arm is transmitted directly to the instrument. The instrument then converts the mechanical energy (vibration acceleration) into an electrical signal.

Vibration is characterized by acceleration in multiple directions. The International Organization for Standardization (ISO) specifies that vibration from a tool should be measured in three directions or axes (x, y, z) as illustrated in Figure A2:

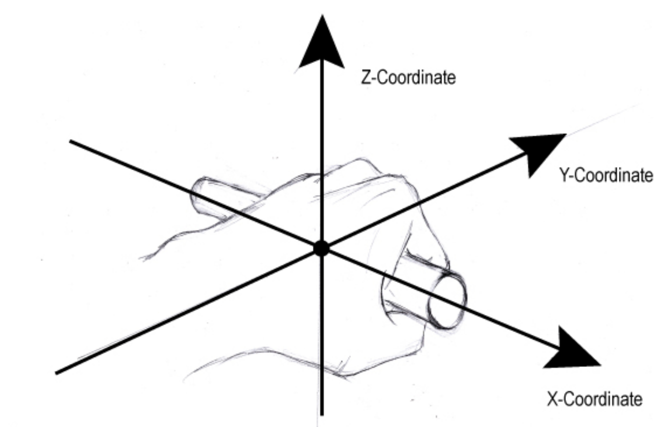

Figure A2 – Axes for Measurement of Hand-Arm Vibration
(Adapted from the *Hand-Arm Vibration Guide*, Griffin et al, 2006)

Transducers are highly directional and therefore only measure vibration in one direction at a time. The transducer should be used to measure the acceleration in each of these three axes. Diagrams and descriptions explaining the specific method for placing the transducer are generally outlined in the equipment manufacturer's instruction manual. Figure A3 provides an example of the transducer placement).

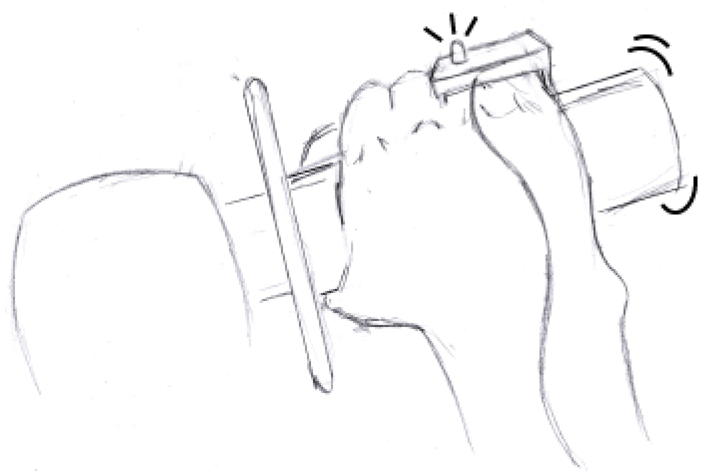

Figure A3 – Placement of the Transducer

Measuring Whole Body Vibration

The specific procedure for measuring whole body vibration can be found in *ISO 2631-1: 1997, Mechanical vibration and shock – Evaluation of human exposure to whole body vibration (Part 1: General requirements).*

For whole body vibration assessments, the transducer is affixed to a seat cushion in the case of seated workers, or to a standing surface in the case of exposure while standing on a vibrating surface. These positions are intended to closely approximate the worker's position during work so that the exposure can be measured.

Unlike hand-arm vibration, whole body vibration is evaluated based on the amount of vibration in all of the axes, rather than in each individual axis. For this reason, specific transducers (e.g. triaxial accelerometers) that are able to integrate vibrations emitted in all directions rather than measuring vibration in each of the axes, are often used to measure whole body vibration exposure.

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