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Occupational Exposure to Vibration—Hazards, Evaluation and Control

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Abstract

Mechanical vibration is known to cause occupational health hazards. Exposure to vibration has potential to cause musculoskeletal disorders. Chronic exposure to hand-transmitted vibration causes occupational disease like vibration induced white finger (VWF). This article describes the harmful health effects caused due to exposure to hand-transmitted vibration (HTV) and whole-body vibration (WBV) and the control measures to minimize the exposure. Specifically, focus is kept on the evaluation of vibration exposure to personnel and occupational exposure limits. To this aim, two case studies are also described for exposure assessment of HTV and WBV.

Keywords: Vibration exposure, hand-transmitted-vibration, whole-body vibration

INTRODUCTION

Vibration is experienced when a body is subjected to forces that cause oscillation about a reference position. It is a form of physical energy that one can perceive when the energy is transmitted to the body parts. Workers in various occupational sectors get exposed to workplace vibration on a daily basis. Occupational exposure to vibration is principally experienced through two ways: hand-transmitted vibration (HTV) or Hand-Arm Vibration (HAV) and whole-body vibration (WBV). The mechanical vibration of a hand-held instrument/equipment is transmitted to the palm, fingers and hand-arm surfaces. HTV exposure can occur through the use of powered hand tools, such as, vibrations from grinding machines, cutting machines, ramming machines, or any impacting tools. On the other hand, when someone stands on a vibrating surface or near a vibrating large machine, sits on a vibrating surface (e.g., vehicle seat) the surface/machine vibration can transmit to the entire body causing WBV. In occupational set-ups, particularly in construction activities, exposure to HTV and WBV is very common which has potential to cause harmful effects on human health.

A number of reviews on the harmful effects of vibration on human health can be found in the literature. In this article, we briefly described the health effects of vibration, its evaluation and control in the workplace. Specifically, we focused on the evaluation of vibration exposure and the implementation of administrative control measures to limit the exposure within occupational exposure limits. In this connection, we also described two case studies on the assessment of HTV exposure from a vibrating hand tool and WBV exposure from operation of a vehicle.

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Effects of HTV and WBV on Human Health

Vibration transmitted to the hand not only affects the body parts at the transmission surface (i.e., palm and fingers) but also the entire hand and arm. This can result in damage or injury to the

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bones, joints and muscles [1]. In severe cases, it may result in arthritis and contractures (tightening of tissues resulting in restricted motion of fingers) [2, 3]. Chronic exposure to HTV affects the nerves and blood vessels of fingers developing vibration-induced white finger (VWF) [4, 5]. The early symptoms of VWF are tingling, numbness, loss of perception and control of the affected fingers [5, 6]. In the advanced stage, this causes blanching (whitening) of the extremities of the fingers [7]. This symptom is often aggravated with exposure to cold and may become irreversible with continuing exposure to vibration [6].

WBV causes discomfort to the exposed workers. Severe exposure may cause musculoskeletal pains in neck and back [8, 9]. Studies conducted on bus and truck drivers reported that exposure to WBV contributed to various musculoskeletal disorders [10, 11]. Chronic exposure to WBV may affect the normal physiological functions of body system resulting in a number of health disorders including cardiovascular disease, digestive problems, development of various neuropathies and motion sickness [12–14].

Evaluation of Vibration Exposure

Exposure to human vibration is measured as vibration acceleration rather than displacement or velocity as instrumentation is more convenient. An accelerometer is used as the sensing element in human vibration measurement system which measures vibration amplitude as well as its frequency. As vibration is a vector quantity, it is measured along the three orthogonal directions. For that reason, generally a tri-axial accelerometer is used for measuring vibration acceleration along three orthogonal axes. Human hand and the whole body are not equally sensitive to all frequencies of vibration. For example, the sensitivity of HTV is the highest around 8–16 Hz [15]. Therefore, the measured vibration is weighted using a frequency weighting network (as per ISO 5349-1:2001 for HTV and ISO 2631-1:1997 for WBV) to mimic the human response to the vibration.

For measurement of HTV exposure, the accelerometer is placed at the contact surface (e.g., palm) of hand and vibrating tool. As per ISO 5349-1 recommendation, the frequency-weighted root-mean-square (r.m.s.) acceleration is measured in the three orthogonal directions: one axis with the arm and in the two other directions in the plane of tool-hand contact surface. The vibration total value, a_{HTV}, is expressed as the root-sum-of-squares of the three components (Eq. 1).

$$a_{HTV} = (a_x^2 + a_y^2 + a_z^2)^{\frac{1}{2}} \quad (1)$$

Where, a_x, a_y and a_z are the r.m.s. frequency-weighted component accelerations along x, y and z axis, respectively.

In case of WBV measurement, the accelerometer is placed at the interface of vibrating source and the body part. For example, in measurement of exposure to vehicle drivers, the accelerometer (often called seat pad) is placed at the buttock-seat interface. Similar to the measurement of HTV, the frequency-weighted acceleration is measured simultaneously in all three directions, where z-direction is always along the main body axis (i.e., it is vertical to the seat or floor plane for measurements at seat), the x-direction is aligned with the fore-and-aft motion and the y-direction with a side-to-side motion. Unlike HTV measurement, frequency weightings for WBV are different for x, y, and z-direction.

Occupational Exposure Limits

The American Conference of Governmental Industrial Hygienists (ACGIH) prescribes the Threshold Limit Values (TLV) for HTV as a function of exposure duration as shown in Figure 1(a) [16]. Here, in case of HTV exposure, the TLV refers to the daily vibration exposure (i.e., 8-hour energy equivalent total value) of 5 m/s^2 with the belief that most workers may be exposed repeatedly at this level without progressing beyond Stage 1 of the Stockholm Workshop Classification System for VWF (Stage 1 represents the mild grade which is occasional attacks affecting only the tips of one or more fingers).

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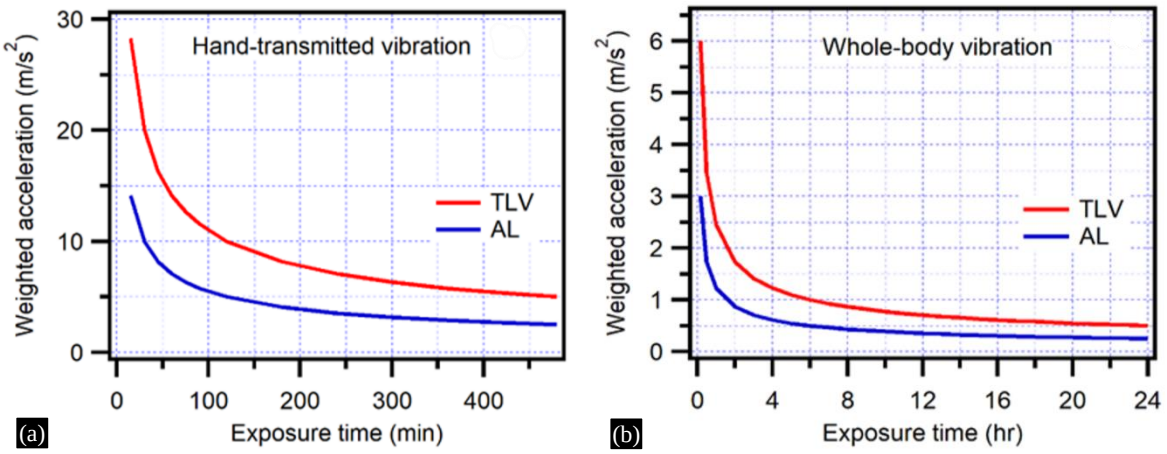

Figure 1. Threshold Limit Values (TLV) and Action Limits (AL) for exposure to (a) HTV and (b) WBV as a function of exposure time. The area between TLV and AL is considered as the "caution zone".

It is to be noted that the TLV values should not be considered as the sharp demarcation of the safe level; individual susceptibility towards developing VWF may be different. Along with the TLV, Action Levels (AL; refers to the 8-hour energy equivalent total value of 2.5 m/s^2) are also recommended at which the risk of developing symptoms is very low for the large majority of workers. The area between TLV and AL is considered as the "caution zone". The exposure within caution zone demands additional control measures such as use of Personal Protective Equipment (PPE). Similar to HTV, the TLV and AL of WBV exposure is also recommended by ACGIH (Figure 1(b)).

CONTROL MEASURES

Occupational exposure to vibration can be minimized through a number of means, e.g., engineering control measures, administrative procedures and use of PPEs.

Engineering Control

Typical engineering control measures are the selection of machines of low vibration level, proper installation of machine to reduce vibration, use of anti-vibration tools, etc. Periodic maintenance of machines, such as lubrication of rotating parts, replacement of damaged parts also helps to reduce the vibration levels. Various vibration isolation techniques, i.e., isolating an object from the source of vibration by active as well as passive means are also in use [17, 18]. Active vibration isolation employs electric power, sensors, actuators, and control systems for vibration isolation, whereas passive isolation includes use of vibration damping elastomeric materials, spring isolator, etc. Use of equipment with good ergonomic design can also help to reduce exposure to vibration. Design of driver's seat has been shown as an important predictor of exposure to vibration by several studies [19, 20].

Administrative Control

Although the control of vibration exposure through engineering means is always desirable, it may not be practicable in many circumstances. In such cases, exposure to vibration should be controlled by administrative procedures. The exposure should be kept as low as reasonably practicable. This can be achieved by reducing the exposure time and limiting the exposure within acceptable levels (i.e., occupational exposure limits). Workers should be made aware of the health effects of vibration. Adequate training on the effectiveness of engineering control measures, safe work procedures and use of PPEs is essential.

Personal Protective Equipment

Anti-Vibration Gloves (AVG) are used as PPE for reducing the exposure to HTV. AVGs serve as cushions which act as simple passive suppression systems between the vibrating tools and hands [21].

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AVGs are lined with specific materials that attenuate vibration of hand tools transmitted to the hand. More clearly, vibration damping materials (e.g., viscoelastic material, air pockets) are used between hand tools and palm. The effectiveness of AVGs depend on several factors: operating conditions of equipment/tool, direction of vibration, frequency components of vibration, nature of jobs, individual differences in fitting the gloves, etc. Nevertheless, the effectiveness of AVGs to reduce the exposure to HTV has been questioned [22]. Specifically, AVGs are not much effective in reducing vibration exposure from low-frequency tools such as rammers, vibrating forks, or pavement tampers.

CASE STUDY-I

Assessment of Exposure to HTV from Demolition Hammer

The case study is the assessment of exposure to HTV during concrete demolition activity in an excavation work. A high speed (1750 W, impact rate 1300 bpm, 16.5 kg) electric demolition hammer was being used for demolition. The equipment was provided with rubber padding on the handle to reduce the effect of vibration or dampen any shocks produced, so as to enhance the level of comfort while working with the equipment. Measurement of HTV was carried out using a six-channel human vibration meter and analyzer (Make: SVANTEK, Model: SV 106), which meets requirements of ISO 8041-1:2017 standard and it has measurement standards according to ISO 2631-1, 2 and 5, ISO 5349 and directive 2002/44/EC of European Parliament. In this case, vibration was measured using two tri-axial accelerometers: one was attached to the handle of the equipment and the other was worn by the worker on palm. A clamping ring was used to fix the accelerometer on the equipment and another accelerometer was worn on palm using a strap. These accelerometers were connected with the control unit through the integrated cables. The accelerometers measure the vibration along three orthogonal axes (Figure 2). The measured values of acceleration are shown in Table 1.

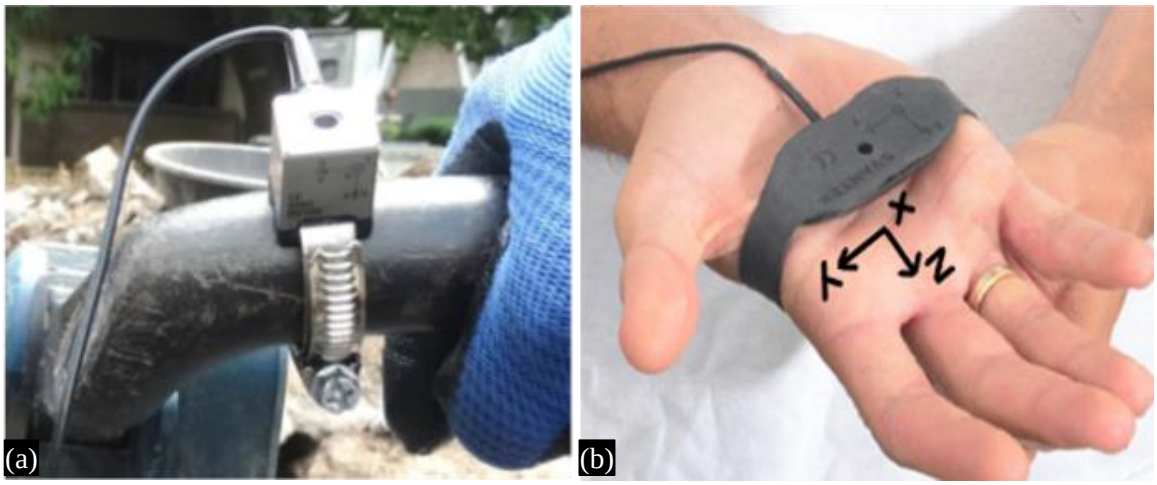

Figure 2. Mounting of tri-axial accelerometer on (a) the handle of demolition hammer and (b) on palm of hand.

Table 1. Magnitude of vibration at equipment handle and on palm of worker during use of the demolition hammer

Measurement Location	Axis	Vibration magnitude (acceleration; m/s^2)
At Handle of hammer	x	15.2
	y	4.2
	z	9.5
On Palm	x	11.1
	y	4.1
	z	8.7

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Following the equation 1, the vibration total value, a_{HTV} at the handle of the hammer and on palm are 18.4 and 14.7 m/s^2, respectively. It was noted that the measured vibration level values vary significantly with location of the sensor (accelerometer). Hence, it is desirable to place the accelerometer as close to human body as possible to give a realistic picture of exposure to vibration. The measured vibration exposure values during concrete demolition exercise were higher than that of during chiseling operation (13 m/s^2 as per tool vibration data provided by the manufacturer).

It was learnt that the demolition hammer was being operated for maximum duration of 45 minutes. Measured weighted acceleration of 14.7 m/s^2 for 45 minutes is within TLV (16.3 m/s^2; refer Figure 1(a)) for 45 minutes exposure and workers are not vulnerable to elevated health risk. However, this value falls in the health guidance "caution zone" which indicates that vibration level is significant and therefore additional preventive action must be taken. The workers who perform this activity should be made aware of work-rest cycle concept to avoid ill effects of vibration in the long run. Furthermore, we analysed the acceleration on palm of the worker at different 1/3-octave band centre frequencies (Figure 3). It revealed that the peak vibration was around 1000 Hz. It means that the contribution of high frequency component to the total vibration is greater. Therefore, use of AVGs may be useful to reduce the vibration exposure.

CASE STUDY-II

Assessment of Exposure to WBV from Operation of Vehicle

Exposure of a vehicle (passenger car) driver to WBV was measured using a tri-axial accelerometer. Acceleration was measured at the buttocks-seat interface, i.e., the driver seated on the accelerometer. There are two different methods of assessment of WBV under ISO 2631-1; either r.m.s. acceleration or Vibration Dose Value (VDV) that can be selected based on the value of Crest Factor (CF). CF is the ratio of peak and r.m.s. acceleration. In case of CF $\leq$ 9, the evaluation with r.m.s. acceleration is normally sufficient. However, in case of CF > 9, the RMS method may underestimate the effects of vibration and therefore, VDV is recommended for evaluation of vibration exposure.

In the present study, the value of CF is less than 9. Therefore, we selected the r.m.s. method for evaluation. The magnitude (r.m.s. acceleration) of vibration measured along the three axes is shown in Table 2. It was learnt that the duration of driving is around 4 hours a day. Therefore, the measured acceleration values are well below the ACGIH recommended TLV for 4-hrs exposure duration (Figure 1(b)).

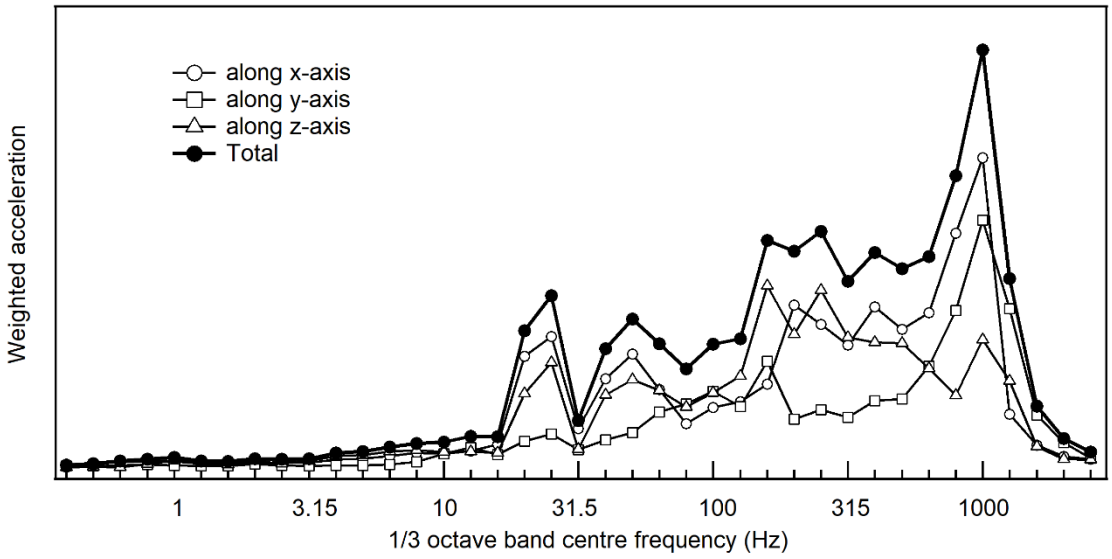

Figure 3. Weighted acceleration measured on palm at various 1/3 octave band centre frequency.

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Table 2. Whole body vibration of a vehicle driver

Measurement Location	Axis	Vibration magnitude (acceleration; m/s^2)
Buttocks-seat interface	x (forward-backward)	0.391
	y (left-right)	0.340
	z (vertical)	0.480

CONCLUSION

Exposure to HTV and WBV has potential to cause harmful effects on human health. In addition to engineering control methods, limiting exposure duration within occupational exposure limits and use of PPEs are followed to minimize the harmful outcomes of vibration exposure. The case studies show typical assessment methods of HTV and WBV during use of a vibrating hand tool and driving a vehicle, respectively. We believe that this article will help particularly the industrial hygienists to evaluate and assess occupational exposure to vibration.

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