Measurement 47 (2014) 64–77

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

# An examination of the handheld adapter approach for measuring hand-transmitted vibration exposure

Xueyan S. Xu, Ren G. Dong *, Daniel E. Welcome, Christopher Warren, Thomas W. McDowell

*Engineering & Control Technology Branch, National Institute for Occupational Safety and Health, 1095 Willowdale Road, Morgantown, WV 26505, USA*

ARTICLE INFO

*Article history:*
Received 16 October 2012
Received in revised form 22 July 2013
Accepted 19 August 2013
Available online 28 August 2013

*Keywords:*
Hand-arm vibration
Hand-transmitted vibration
Vibration measurement
Vibration dosimeter
Handheld adapter

ABSTRACT

The use of a handheld adapter equipped with a tri-axial accelerometer is the most convenient and efficient approach for measuring vibration exposure at the hand-tool interface, especially when the adapter is incorporated into a miniature handheld or wrist-strapped dosimeter. To help optimize the adapter approach, the specific aims of this study are to identify and understand the major sources and mechanisms of measurement errors and uncertainties associated with using these adapters, and to explore their improvements. Five representative adapter models were selected and used in the experiment. Five human subjects served as operators in the experiment on a hand-arm vibration test system. The results of this study confirm that many of the handheld adapters can produce substantial overestimations of vibration exposure, and measurement errors can significantly vary with tool, adapter model, mounting position, mounting orientation, and subject. Major problems with this approach include unavoidable influence of the hand dynamic motion on the adapter, unstable attachment, insufficient attachment contact force, and inappropriate adapter structure. However, the results of this study also suggest that measurement errors can be substantially reduced if the design and use of an adapter can be systematically optimized toward minimizing the combined effects of the identified factors. Some potential methods for improving the design and use of the adapters are also proposed and discussed.

Published by Elsevier Ltd.

## 1. Introduction

Various powered hand tools are widely used in many industries. Prolonged, intensive exposure to vibration generated from some of these tools may cause hand-arm vibration syndrome [1,2]. Hand-transmitted vibration exposure has also been identified as a contributing factor towards developing carpal tunnel syndrome [3]. To control hand-transmitted vibration exposure, the International Organization for Standardization has set forth a standard for the measurement, evaluation, and assessment of the exposure [4,5]. The standardized daily exposure dose is termed as A(8), and its value depends basically on two variables: (i) vector sum of the frequency-weighted accelerations in three orthogonal directions measured at or near the area where each hand is in contact with a vibrating tool or machine; and (ii) daily exposure duration. While the international standard does not recommend any specific target for the exposure control, two targets are recommended or required by some countries in their national counterparts to the international standard [6,7]. The targets are termed as Daily Exposure Action Value (DEAV = 2.5 m/s$^2$) and Daily Exposure Limit Value (DELV = 5.0 m/s$^2$). While workers should not be exposed to A(8) values beyond the DELV, employers should initiate a program to reduce exposures if a worker's exposure dose exceeds the DEAV [6,7]. The effective and appropriate implementation of the standard or Directive depends partially on whether the daily vibration exposure dose can be conveniently and reliably measured. This remains an important issue for further studies.

* Corresponding author. Address: ECTB/HELD/NIOSH/CDC, 1095 Willowdale Road, MS L-2027, Morgantown, WV 26505, USA. Tel.: +1 (304) 285 6332; fax: +1 (304) 285 6265.

*E-mail address:* RDong@cdc.gov (R.G. Dong).

0263-2241/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.measurement.2013.08.037

Hand-transmitted vibration could vary greatly with many factors such as tool model, tool condition, location and direction on a tool, working material, tool user's biodynamic properties, applied hand force, and working posture [8–10]. The standards recommend that vibration exposures be measured at workplaces under actual working conditions [4,7]. While it is usually unreliable to determine exposure durations based on workers' self-reports [11–13], the exposure duration for the operation of each tool can be accurately measured using several simple methods such as video recording or activity sampling. These approaches can be time-consuming and expensive for long-term measurements. Furthermore, the vibration magnitude could vary with time, and workers can use various tools during each shift; it is desired to determine daily exposure dose by measuring the exposure dose history over an entire shift. To account for day-to-day variations, it is also desired to measure long-term exposure dose history. The history data may also be useful for studying the effects of work-rest patterns on the development of vibration-induced disorders. Such measurements require a convenient, reliable, robust, and inexpensive miniature dosimeter that presents minimal interference with work activities during its operation.

As demonstrated in some studies [14,15], attaching an accelerometer to a location on the hand is probably the most convenient approach for measuring hand-transmitted vibration exposures. The most desired location is at the wrist because it produces minimal interference with hand movements, similar to activity wrist watches. While this approach is acceptable for quantifying exposure duration with sufficient accuracy [16], it may not be generally acceptable for measuring vibration magnitude since much of the hand-transmitted vibration may be attenuated before it reaches the wrist; the near-unity bandwidth of wrist vibration transmissibility is very limited [17–19]. The bandwidth of the on-the-hand approach can be increased by attaching the accelerometer on the dorsum of the hand or a finger, as was done in some studies [14,15]. The data from other studies indicate that the near-unity transmissibility on any part of the hand is usually limited to frequencies below 150 Hz [19–21], except in the fingertip area where it is difficult to fix a conventional tri-axial accelerometer. Furthermore, the vibration transmissibility on the hand in the three orthogonal directions may vary greatly with the specific location, subject, hand force, posture, handle shape and dimension. Therefore, although on-the-hand approaches have some unique advantages, this technique is not recommended in the standardized method for measuring vibration exposure.

The standardized method requires the attachment of an accelerometer on the tool handle to measure the hand-transmitted vibration [4,7]. Four attachment approaches (screwing, gluing, using a hose clamp, or using a handheld adapter) are recommended in the standard [5]. Each of them has unique advantages and disadvantages [22,23]. The handheld adapter approach is most convenient and efficient. With this approach, the accelerometer can also be positioned at the most desired location: the central area of hand-handle interference. Many adapter configurations have been designed [22,24–26]. Some of them have also been adopted in the standard [5]. The adapter approach has also been incorporated into handheld vibration dosimeters [27,28], which can make the measurement very convenient and efficient. On the other hand, the adapter approach is generally considered as the least reliable among the four recommended approaches [22,23]. While the adapter approach is not generally recommended for the measurement of vibration on engineering structures [29], it is considered as the last choice in the standard for measuring the hand-transmitted vibration exposure [5]. Although some studies have been performed to optimize adapter designs [22,26], the exact sources and mechanisms of the measurement errors and uncertainties using the adapter approach have not been clearly identified. In particular, there are few reports on the effects of hand biodynamics on the measurement. Furthermore, while the reported studies primarily investigated fingers-held adapters [22,23,26], it is unclear whether other adapters can provide better measurements. It is also unclear whether and how the adapter approach can be further improved.

Based on this background, the objectives of this study were to identify the major sources of measurement errors and uncertainties using the adapter technique, to enhance the understanding of the mechanisms involved with measurement errors, and to explore improvements in the adapter method. While some preliminary results were briefly reported at a conference [30], the completed study is presented in this paper.

## 2. Methods

### 2.1. Experiments

Fig. 1 shows five handheld adapters that have been examined in this study, together with their designed holding positions on the hand. Their sources and major features are listed in Table 1. Adapter 2 has two foot options: (A) with the original foot design of the fingers-held dosimeter and (B) with a modified foot similar to that of the fingers-held adapter (Adapter 3), which adapts better to the instrumented handle. Each of the adapters was equipped with a tri-axial accelerometer.

Five healthy male subjects (ages 19 to 31) participated in the experiment. Their major anthropometries are listed in Table 2. The study protocols were reviewed and approved by the NIOSH Human Subjects Review Board. The experimental setup and operator postures used in this study are shown in Fig. 2. Although a single-axis shaker was used to provide the vibration input to the hand along the forearm or $z$-axis, some vibrations could also be generated in the other two orthogonal axes ($x$ and $y$) when a hand grips on the handle [31]. The instrumented handle is equipped with a tri-axial accelerometer (PCB, 356A12), which is firmly affixed to the inner surface of the handle base [31]. The instrumented handle is also equipped with a pair of force sensors (Kistler, 9212) to measure the applied grip force. A commercial force plate (Kistler, 9286AA) was used to measure the applied push force. The fundamental natural frequency of this instrumented handle is above 1700 Hz [32].