AN ACCURATE METHOD FOR MEASURING THE EXPOSURE DURATION OF HAND-TRANSMITTED VIBRATION

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Abstract

Daily vibration exposure duration of a worker is an essential factor that determines the vibration 'dose' input to a worker's hands for risk assessment of hand-arm vibration syndrome. Accurate measurement of pattern and duration of vibration exposure is essential for more reliable assessment of exposure on the basis of the dose-response relationships. This study describes the design and performance of a compact measurement system comprised of hand- or wrist-mounted accelerometers and a commercially available data logger. The proposed measurement system is assessed through a series of measurements performed in the laboratory and the field. Preliminary test results suggest that the proposed measurement system can provide an effective measure of the vibration dosage, duration and pattern of vibration exposure. The experience gained from the study also provided important guidelines for developing a more reliable and convenient measurement device for applications involving field assessments of hand-transmitted vibration.

1. Introduction

Prolonged occupational exposure to hand-transmitted vibration may cause hand-arm vibration syndrome (HAVS). Daily exposure duration of a worker is a critical factor that determines the vibration 'dose' input to a worker's hands (ISO-5349, 2001). Apart from the total exposure duration, the exposure-rest patterns are also believed to influence the health risks posed by hand-transmitted vibration. Although the effects of exposure patterns require further investigations, the need for accurate measurement of exposure duration and pattern has been identified as being essential for effective risk assessment analyses. A convenient and reliable method for accurately measuring the exposure pattern and the total duration is thus highly desirable to conduct appropriate risk assessment.

The daily vibration exposure duration is often estimated on the basis of the workers' claims of exposure duration, which may not be considered reliable. Videotaping or on-site observation by investigators can provide an accurate measure of the exposure duration and additional significant information related to the modes of operation. This approach, however, involves manual videotaping and data processing, and is extremely demanding on the human resources. Acoustic data loggers may also be employed to monitor the exposure duration through acquisition of noise generated from a power hand tool. This approach, however, would pose difficulties in isolating the tool-generated noise signal from those arising from other sources in the workplace. Moreover, the tool noise may not always coincide with the vibration exposure, specifically when the tool idles.

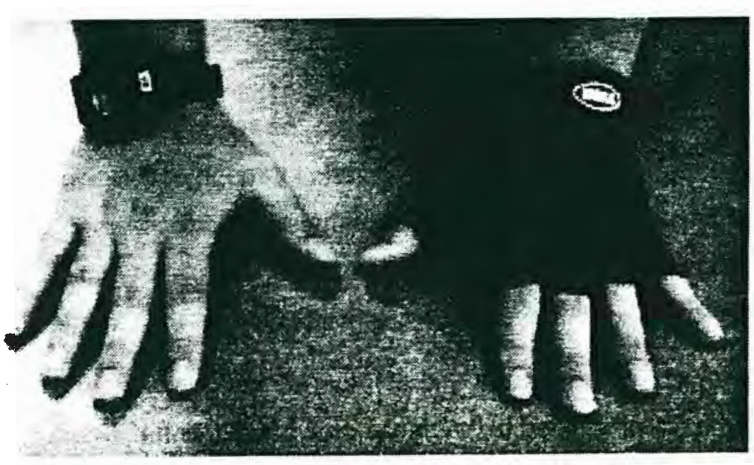
An accurate measurement of the pattern and duration of the vibration exposure necessitates direct measurement of vibration transmitted to the hands over the duration of representative work shifts.

Owing to the high frequency nature of hand-transmitted vibration and requirement for appropriate sampling rate, a direct measurement and acquisition system would, in general, require high on-board memory or data storage capacity. Alternatively, a commercially available human vibration measurement or monitoring system may be employed in conjunction with a wrist-mounted accelerometer to achieve a direct measurement of the exposure duration. In this study, a data logger is configured using a human vibration meter and a series of field and laboratory measurements are performed to examine the feasibility of the proposed device.

2. Measurement System and Experimental Method

2.1 Measurement system

The proposed system consists of a human vibration meter (Larson-Davis, HVM100), a signal connection cable, a triaxial accelerometer (PCB, 339B24), an accelerometer adapter for fixing the accelerometer at the desired position, and a jacket for holding the meter and the connecting cables. The human vibration meter is relatively compact (2.5x8.3x15.2 cm) and weighs only 279 grams. It can acquire and analyze the signals from a triaxial accelerometer and integrates the signal conditioning, weighting filters and computation modules to obtain the weighted and unweighted root-mean-square (rms) values of the measured signals. The meter also stores the rms data with the maximum saving rate of 1 Hz. At this rate, it could acquire the vibration signals continuously for 6 hours and 40 minutes. The data acquisition and storage duration could be increased to more than 13 hours, when the saving rate is reduced to 0.5 Hz. The two AA batteries used in the meter can supply sufficient power to perform continuous measurements for more than 8 hours. In this study, two accelerometer installations were considered. A triaxial accelerometer was installed within a modified wrist watch to monitor the exposure duration through measurement of wrist vibration. An accelerometer was also installed within a glove adapter, realized by modifying a bicycle glove by sewing a small pocket on the back of the glove. Its corresponding location on the hand was right behind the knuckle of the middle finger. Pictorial views of the watch and glove adapters are shown in Figure 1. The meter was contained in the breast pocket of a special work jacket, with accelerometer cables attached inside the sleeve of the jacket so that the cables did not interfere with the operator's tasks.



2.2 Laboratory Testing

The frequency response characteristics of the wrist-mounted and glove-mounted accelerometers were investigated in the laboratory. A vibration test system (Uholtz-Dickie S032) was employed to provide broadband white noise vibration (3 g, 8-1250 Hz) as input in the test. The experiments were performed using three male subjects, and frequency response of each accelerometer was measured three times for each subject. Each subject was advised to grip a 40 mm diameter instrumented handle, developed on the basis of the design outlined in ISO-10819 (1996). The experiments were performed with both accelerometers (wrist and glove-mounted), while the subjects imparted specified levels of push and grip forces. The push force was measured using a force plate (Kistler 9286AA), while the grip force was measured using the strain gage transducer integrated within the handle. Each subject was asked to grasp the instrumented handle using one of his hands with a specific arm posture (elbow angle = 90º±10º), grip force (30 N), and feed force (50 N), using the visual displays of the measured forces.

2.3 Field Testing

A field test was conducted to evaluate the applicability and performance of the proposed measurement system. The tests were conducted at three road repairing sites. Three professional male workers participated in the tests. The two of the work sites employed jackhammers for breaking the damaged asphalt pavement and concrete curb, respectively, while the third site employed a plate saw to cut sections of the damaged pavement. The experiments were performed with both accelerometers to record the exposure duration and pattern. Accelerometers were also mounted on the tool handles to acquire the tool-handle vibration during a part of the exposure duration.

3. Test Results

The data acquired from laboratory measurements under broad-band vibration excitation was analyzed to derive the vibration transmissibility of the hand using the glove adapter and the wrist accelerometer. The data obtained from three different trials was averaged in the third octave frequency bands to determine the mean vibration transmissibility of the hand. The vibration transmissibility was computed on the basis of overall rms acceleration (vector sum of accelerations along three directions) measured at either the adapter or the wrist watch. The mean vibration transmissibility derived for each subject with the glove adapter is shown in Figure 2. The results show amplification of vibration in the frequency range of 25 to 125 Hz, and considerable attenuation at frequencies greater than 500 Hz. The variation in the vibration transmissibility characteristics of three subjects is most likely attributed to differences in their hand sizes, as shown in Table 1. The tightness of the glove thus differed considerably from subject to subject when using the same glove adapter. The results suggest that the resonant transmissibility tends to decrease with increasing hand size or tightness of the glove, as it is evident from the results shown in Figure 2. The general trend of the vibration transmissibility, especially measured with Subject 3, agrees with that reported by Sorensson and Lundstrom (1992), who used a laser vibrometer in their measurements.

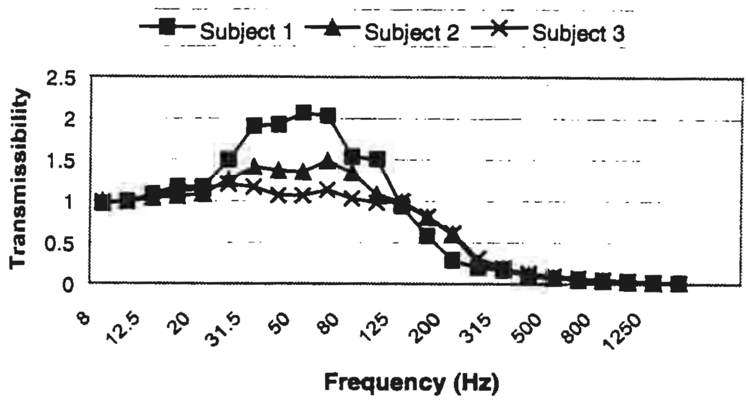
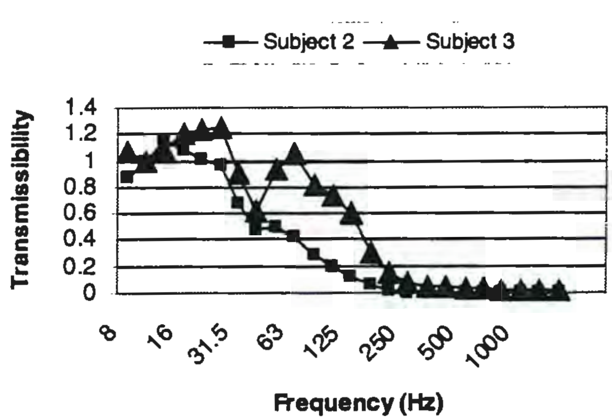


Figure 2. Total vibration transmissibility with the glove adapter

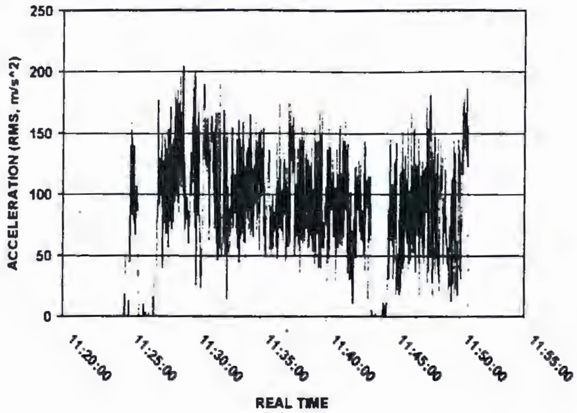
Table 1. Subject relevant hand dimensions

Subject	hand width	Hand thickness
1	8.2 cm	2.8 cm
2	8.4 cm	2.9 cm
3	8.9 cm	3.1 cm

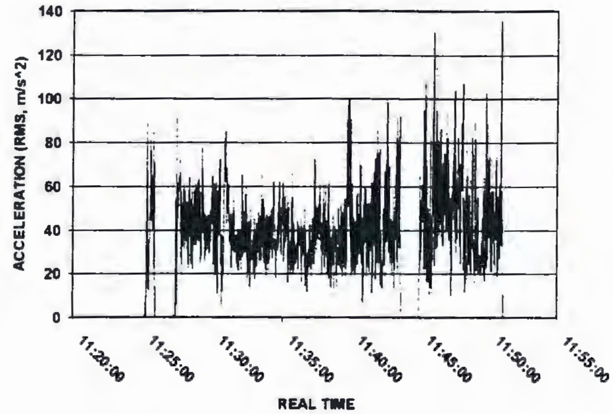
The mean total vibration transmissibility characteristics, derived from the measurements performed with the wrist watch accelerometer, are shown in Figure 3. Only two subjects participated in these tests. The results show slightly amplification in the frequency range of 10 to 30 Hz, and significant attenuation at frequencies greater than 300 Hz. These general trends in the vibration transmissibility agree with those reported in the literature (Reynolds and Angevine, 1977; Cherian et al., 1996).



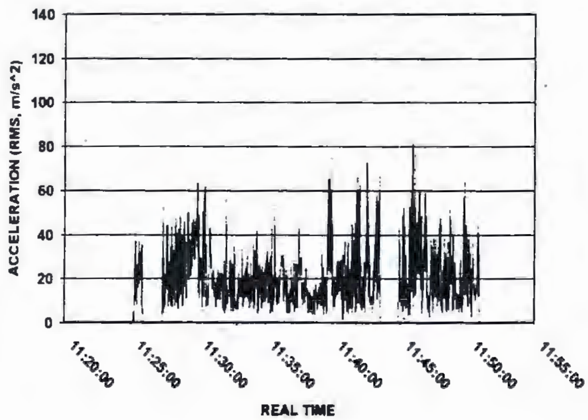
a. Total acceleration measured on the plate saw the front handle



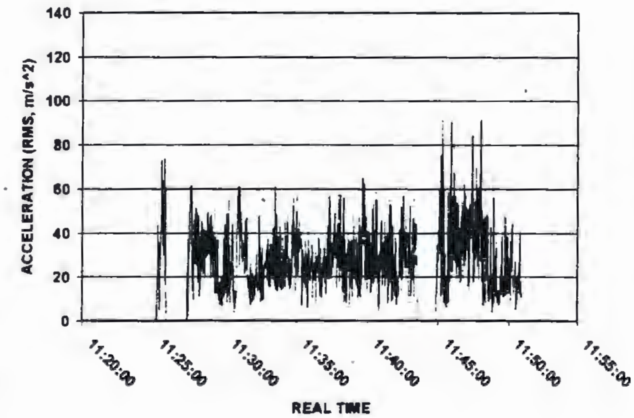
b. Total acceleration measured on left hand with glove adapter



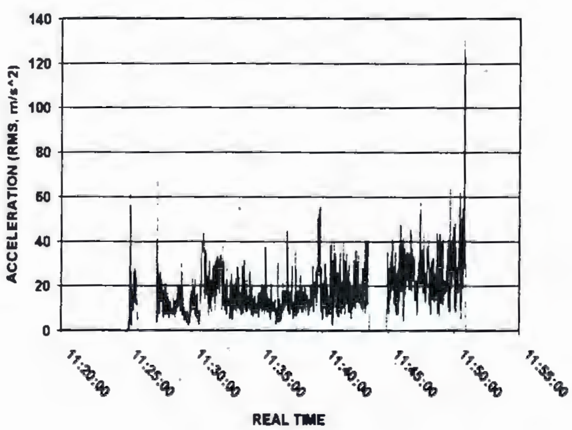
c. Acceleration measured in X-axis on the glove adapter



d. Acceleration measured in Y-axis on the glove adapter



e. Acceleration in Z-axis measured on the glove adapter



f. Glove adapter coordinate system

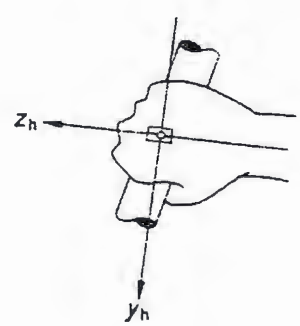
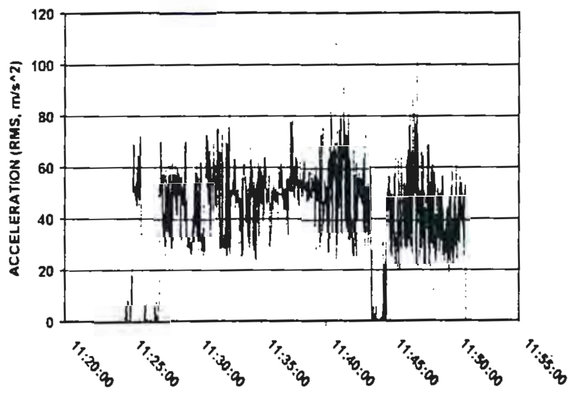
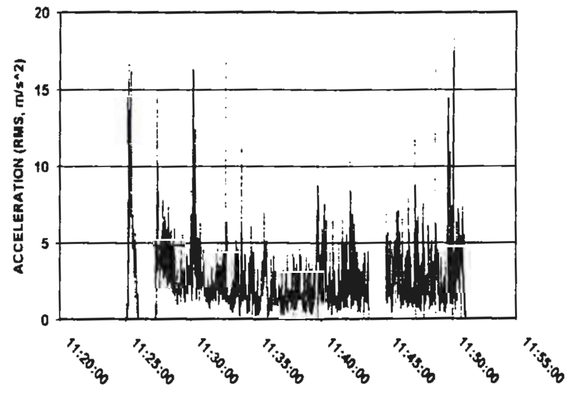


Figure 4. Samples of the unweighted accelerations measured on the tool and the glove adapter

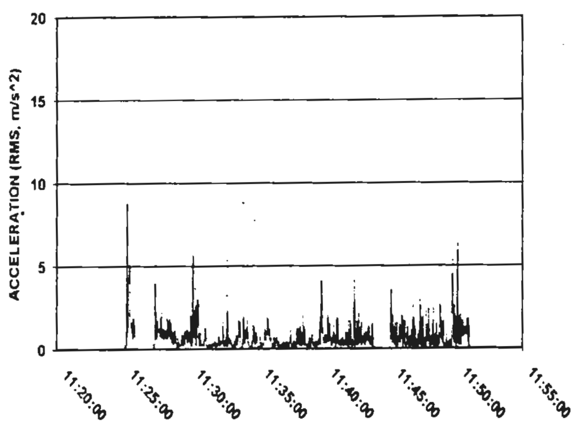
a. Total acceleration measured on the tool rear handle



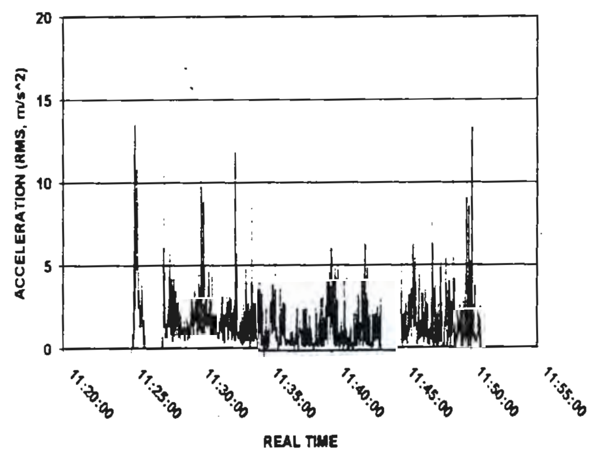
b. Total acceleration measured on the watch adapter



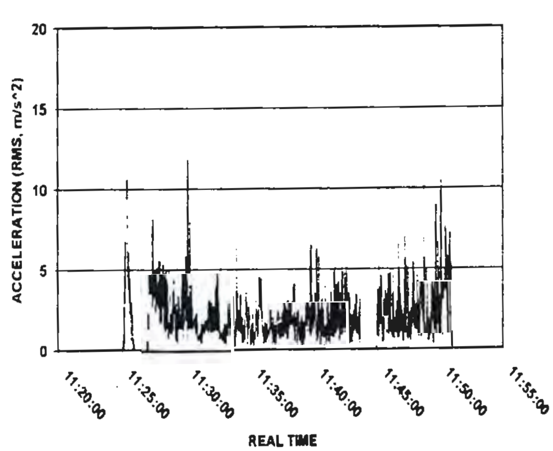
c. Acceleration in X-axis on the watch adapter



d. Acceleration in Y-axis on the watch adapter



e. Accelerations in Z-axis on the watch adapter



f. Watch adapter coordinate system

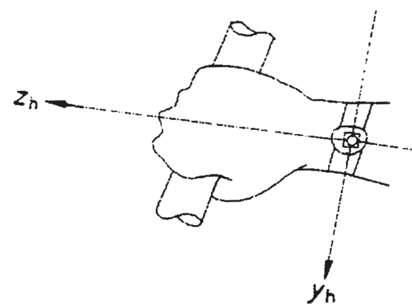


Figure 5. Samples of the unweighted accelerations measured

of the body. The subjects held the front handle with their left hand, and the rear handle with their right hand. Figures 4 and 5 show portions of the time histories of the unweighted root-mean-square (rms) accelerations measured at the front and rear handles, acquired from the human vibration meter with its built-in 6.3-1250 Hz band filter. Figure 4 also illustrates the coordinate system used in the study. The total vibration measured on the front handle (Figure 4a) is higher than that measured at the rear handle (Figure 5a). The average transmissibility of the total vibration on back of the hand (glove adapter) is approximately 50%, which can be estimated from the results shown in Figures 4a and 4b. The results shown in Figures 5a and 5b demonstrate that the average vibration transmissibility at the wrist is less than 10%. The vibration components in all the three axes are measurable both on the back of the hand and at the wrist, as shown in Figures 4c to 4e and 5c to 5e. The vibrations measured at both locations of the hand are generally not proportional to the corresponding tool handles. The vibration exposure and rest periods, however, can be easily identified with any of the vibration components or the total vibration measured on the hand or at the wrist. The weighted rms acceleration on the tool handle measured with the standard hand-arm weighting filter built-in the human vibration meter was generally less than 10 m/s^2 but its unweighted acceleration was usually over 60 m/s^2. This suggests that the dominant vibration of the saw handle most likely occur in a relatively high frequency range.

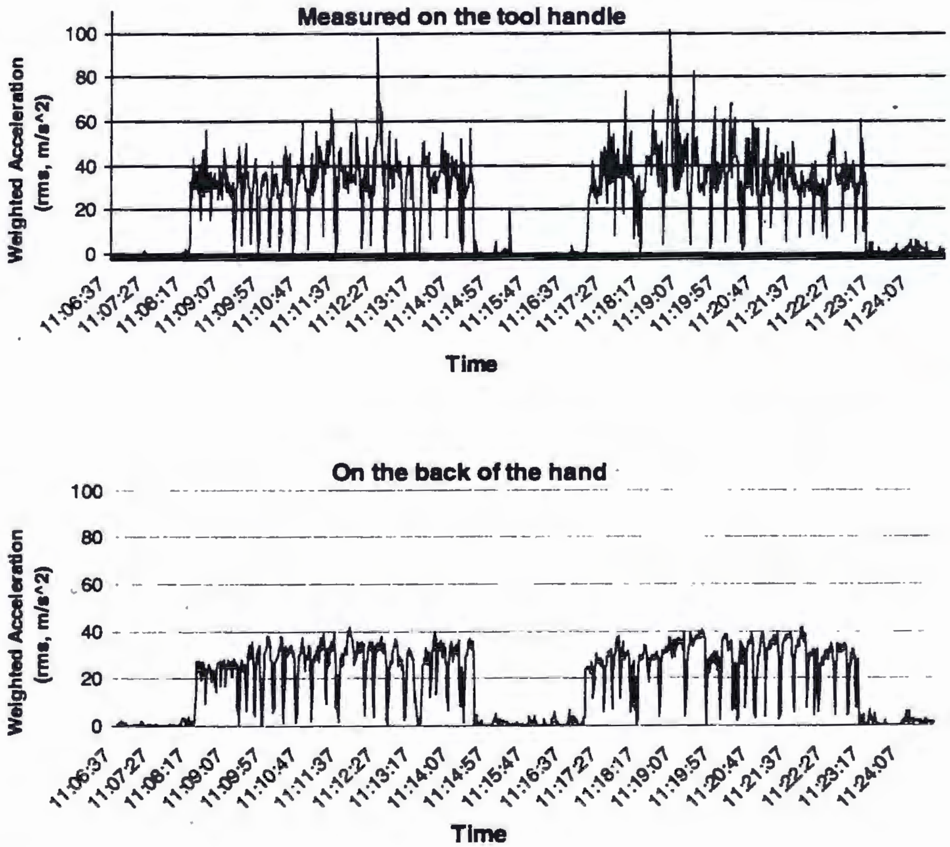


Figure 6. Weighted accelerations on a jackhammer and on the back of the hand

The vibrations measured on the hands from the jackhammer tests were significantly higher than those attained from the plate saw, which makes it relatively easier to identify the exposure and rest durations. The weighted rms values of the accelerations measured on the handle and the back of the hand show reasonably good correlation (Figure 6), which were acquired from the human vibration meter with its built-in hand-arm weighting filter.

4. Discussions

The measurement of vibration on the back of the hand has been proposed as an alternate approach to the standard measurement method for exposure (Tokita and Ohkuma, 1990). While this method permits partial consideration of the contributions due to grip and feed forces, the subjects tend to adapt to the sensors at the back of their hand better than to the palm adapter. This methodology, however, assumes that the magnitude of vibration on the back of the hand is identical to that at the hand contact surface at a certain coupling force. It has been reported that this assumption is valid for frequencies below 150 Hz under single axis vibration with a power gripping hand posture (Tokita and Ohkuma, 1990). The measurement method may be considered appropriate if the total vibration transmissibility would be unity at such a frequency range, since the current weighting function as specified in ISO-5349 (2001) significantly suppresses the magnitude of vibration at frequencies above 100 Hz. Combining both the measurements of exposure duration and magnitude would significantly increase the value of the test. This study suggests that near unity transmissibility of the total vibration at frequencies less than 150 Hz can be achieved if the accelerometer can be appropriately attached to the back of the hand, as shown in Figure 2. This study also suggests that the method based upon the glove adapter can provide useful information on both exposure duration and vibration magnitude on the types of power hand tools that require direct coupling of the palms of the hands with the tool handles, such as jackhammers.

This measurement method, however, has some limitations. The magnitude of vibration measured on the back of the hand in this study revealed poor correlation with that on the saw handle. This may be partially attributed to variations in the hand-handle coupling force and hand posture during the tool operation. Moreover, the front handle of the plate saw was primarily held or lifted by the fingers during the operation, which may result in lower transmissibility of vibration to the back of the hand, considering that the saw vibration consist of relatively high frequency components. The vibration measured on the back of the hand may thus be considered inadequate for tools that are held or lifted by the fingers, specifically for those with dominant vibration in the relatively high frequency range. An examination of the measured data presented in Figures 4 and 5 suggests that lowest levels of vibration occur along X-axis at the wrist (Figure 5c), and its frequency components are relatively lower. Despite the low magnitudes and lower frequency components of saw plate vibration along this axis, the data can be conveniently used to identify the exposure duration. The results also suggest that a single axis measurement at the wrist may be sufficient for accurate and direct measurement of the exposure duration. The proposed measurement system could thus be significantly simplified by acquiring only single-axis measurement. The measurement based upon unweighted rms acceleration would be preferable for such measurements due to its higher magnitude.

of wearing the instrumented jacket in the summer heat. Ideally, the exposure duration meter would work like a watch, without being noticed by the worker. Moreover, the measurement system based upon the wrist accelerometer causes less interference with the operator's tasks than that based upon the glove adapter with accelerometer on the back of the hand. Many lightweight data loggers equipped with an accelerometer have been commercially available for measuring personal activities over the course of days or weeks. The authors tested several activity meters, however, none of them were considered suitable for the required measurement. The major shortcomings of such systems included their low sampling, which allowed measurements of only low-frequency movements or vibrations. Finally, it should be pointed out that the proposed exposure duration measurement system, especially that based upon the wrist accelerometer, may not be suitable for tools with very high frequency vibration, such as a dental drill.

5. Conclusions

The preliminary test results suggest that the proposed system based on the human vibration meter can provide reliable measurement of the hand vibration exposure duration, and that the human vibration meter together with a single axis acceleration measurement at the wrist can provide an effective measure of the exposure duration for the majority of the power hand tools.

6. References

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