# Chapter 19
# Application of Dampening Accessories for Reduction of Hand-Arm Vibration Exposure

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**Abstract** The study on the ergonomics of the wood cutting process can help to minimize risk injuries during a wood cutting operation. It is also expected that prolonged exposure to hand-arm vibration can lead to the development of the carpal syndrome to the operator. This paper focused on experimenting with the vibrations produced by a jigsaw hand-arm and the effect of dampening accessories on the vibration exposure during the wood cutting operation. The vibration of the tool is measured using a triaxial accelerometer connected to data acquisition system. The triaxial sensor is mounted on the operator's hand with reference to ISO 5349 (2001) guidelines. Three different blades are used to identify different vibration effects to the same hand-arm tool. The results indicate that the usage of blades designed for speed cutting produces the most vibration. The machine vibration improves by adding a silicone rubber with different thicknesses embedded to the glove. Silicone rubber acts as a damper and reduces the hand-arm vibration. The thickness is optimized between acceptable vibration exposure and cutting result. It is found that the optimum thickness for rubber dampening is between 2 and 8 mm. The increase of more than 8 mm rubber dampening thickness not only leads to unacceptable cutting result but also will increase the vibration transferred to human's hand.

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## 19.1 Introduction

Musculoskeletal disorders (MSDs) are a common illness related to prolonged exposure and accounted for 31% of all injury and illness cases in 2015 by the Bureau of Labor Statistics (CA Incidence 2011). The operation of the machinery itself mainly generates vibrations (rotating or reciprocating masses, gas pulsation, aerodynamic phenomena) by the impact of hand-held machinery on hard materials or by the interaction between the machinery and its environment. For example, vibration can be caused by the movement of mobile machinery over rough ground. Machine tools used by construction workers, industry, and agriculture are the most affected by vibration (Eurofound 2017). Furthermore, increasing the feed force will also have effect on vibration (Xu et al. 2021). The use of dampening, especially, damping measures at high frequency range leads to significant vibration reductions in the resonance cases (Wegener et al. 2021).

Several symptoms and prolonged illness have been identified to be related to vibration exposure, on hand-arm, and whole-body systems (Griffin 1991). Clarifying the key sources of workpiece vibrations, identifying and comprehending their features and contributing factors, and creating and using relevant methods and technologies to successfully limit vibration exposure are all important stages toward the goal of intervention (Xu et al. 2021).

The vibration transmitted from a jigsaw machine tool to the operator's hand is varied based on different cutting blades. High-performance blades for faster cutting operation produce more vibration compared to common blades. The machine vibration can be reduced with the use of a dampener that can absorb the transmitted vibration. However, the optimum dampening thickness is required to provide a faster cutting process without reducing any quality of the finished product.

## 19.2 ISO 5349

Each standard supports its own benefits within every industry; however, the common benefits across the certifications include: widened market potential, compliance to procurement tenders, improved efficiency and cost savings, higher level of customer service and therefore satisfaction, and heightened staff moral and motivation (HAV exposure points system ready reckoner note—points formulas).

The ISO 5349-2001 (mechanical vibration—measurement and evaluation of human exposure to hand-transmitted vibration) standard is used to detect hand-arm vibration in the jigsaw wood cutting process. This ISO standard is divided into two parts: ISO 5349-1 (generic requirements) and ISO 5349-2 (special requirements) (practical guidance for the measurement at the workplace). The ISO 5349 standard was developed as a result of research into the technique for collecting data on the human body and categorizing vibration effects in terms of sensitivity to the development of vibration white finger (VWF), also known as Raynaud's illness. In general, the vibration response can be categorized using the frequency, amplitude, direction, time of exposure, and grip force (Joshi et al. 2001). In ISO 5349-1, it specifies the general requirement for the measurement and evaluation of human exposure to hand-transmitted vibration. It is enhanced by the information given in ISO 5439-2, which gives the practical guidance for the implementation of appropriate measurement and evaluation techniques at the work place (ISO 1997).

The scope stated in ISO 5341-1 specifies the general requirements for measuring and reporting hand-transmitted vibration exposure in three orthogonal axes. ISO 5349-1 is also referred as a general requirements for measuring and evaluating human exposure to hand-transmitted vibration which are known to prompt the effect of human expose to hand-transmitted vibration in working conditions. The factors included the frequency spectrum of the vibration, the magnitude of the vibration, and the duration of exposure per working day.

In accordance with ISO 5349-1, the ISO 5349-2 provides guidelines for the measurement and evaluation of hand-transmitted vibration at work. The procedures for taking representative vibration measurements and determining the daily exposure time for each operation were detailed in the guidelines. The purpose of the guided activities are to standardize the experiment so that an 8-j energy equivalent vibration total value can be calculated, which represents everyday vibration exposure in real life. This section of ISO 5349-2 applies to all scenarios in which vibration is delivered to the hand-arm system via hand-held or hand-guided machinery, vibrating workpieces, or controls of mobile or permanent machinery.

## 19.3 Experimental Setup

The experiment uses a jigsaw power tool for the wood cutting process. The vibration is measured in three orthogonal directions: $x$, $y$, and $z$ by using a triaxial accelerometer, as shown in Fig. 19.1. The position of the sensor is referred to the standard guideline from ISO standard 5349-1 (2001).

The experiment is performed for three different blades: basic for wood T111C, wood T144D, and wood and metal T345XF. The T111C basic for wood blades is reasonable for cutting wood and wood products are made up of high carbon steel construction for long life performance. The T144D is relatively fast cutting activities. The blade is made up of high carbon steel material with a T-shank design for maximum grip and stability during the wood cutting process. The blade of T345XF for wood and metal is an outstanding product with bi-metal construction for durability and long life. Figure 19.2 shows the mentioned blades.

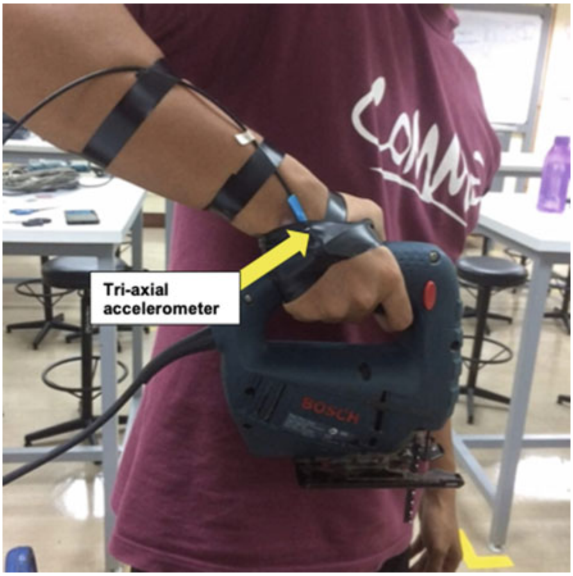


**Fig. 19.1** Actual experimental setup


**Fig. 19.2** Different blades for the same machine tool

## 19.4 Data Collection

Referring to the flow chart shown in Fig. 19.3, the data are acquired from the triaxial accelerometer through connection to the data acquisition system (DAQ) via the PCB triaxial accelerometer cable with three distinguished pins labeled $X$, $Y$, and $Z$, respectively. Following the acquired data from the DAQ, the system converted the analog signal to digital data and transferred the data to the personal computer for meaningful information. The DAQ is performed using the LMS Test Express software known as spectral analysis to measure the vibration signal.

$X$, $Y$, and $Z$ are the representation of acceleration amplitudes in units of $g$. Hence, all the three values must be converted to m/s$^2$ by multiplying the values with 9.81 m/s$^2$

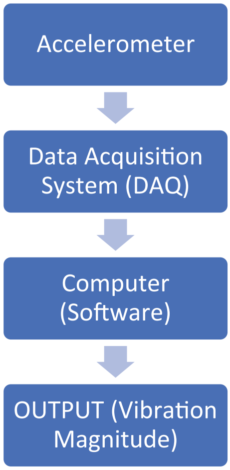


**Fig. 19.3** Flowchart of data acquisition process

in order to get in $a_{RMS}$ value. The final output was represented in form of the root mean square (RMS) acceleration value in terms of vibration magnitude in m/s$^2$ and frequency spectrum in Hz. By following the ISO 5349 standard, the RMS value of acceleration is computed for examining the extent of vibration entering the hand-arm system from the jigsaw. The vibrations are measured in the three orthogonal directions of *X*, *Y*, and *Z*. Each samples were combined into a single value by using the following equation:

$$a_{RMS} = \sqrt{ax^2 + ay^2 + az^2}. \tag{19.1}$$

The result of the average vibration magnitude for each three types of blades is used to determine the daily vibration exposure using the exposure point system as shown in Fig. 19.5. The points for daily vibration exposure for each type of blade are compared to investigate the vibration level of those three different sawing blades.

## 19.5 Result

Laboratory experiments were conducted using the hand machine to obtain the amplitude and frequency values produced by the hand tool machine when using different saw blades. Table 19.1 shows the result in three-axis condition.

In this experiment, the worker is assumed to be exposed to vibration for 3 h in a day. Figure 19.4 shows the compilation of magnitude vibration with reference to the blade type. The vibration magnitude levels are averaged to determine the total vibration magnitude, and then, the daily vibration exposure is determined by using the exposure point system as shown in Fig. 19.5.

**Table 19.1** Collected data from for each blade

| Type of blade | *X*-axis | | *Y*-axis | | *Z*-axis | | Vibration magnitude ($m/s^2$) |
|---|---|---|---|---|---|---|---|
| | Amplitude (g) | Frequency (Hz) | Amplitude (g) | Frequency (Hz) | Amplitude (g) | Frequency (Hz) | |
| T111C | 0.4739 | 223 | 0.3898 | 112 | 0.2335 | 332 | 6.44 |
| T144D | 0.1859 | 113 | 0.6818 | 114 | 0.1297 | 332 | 7.05 |
| T345XF | 0.1292 | 226 | 0.55706 | 114 | 0.2426 | 115.5 | 6.21 |

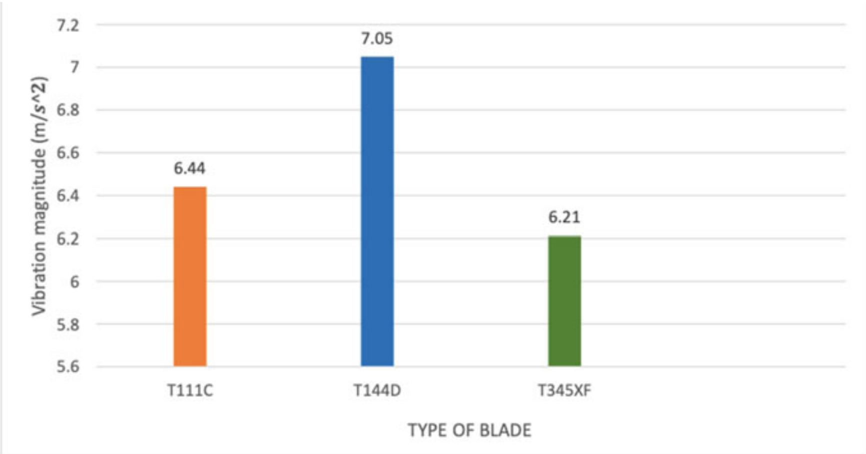


**Fig. 19.4** Vibration magnitude based on type of blade

Referring to the exposure point system by the ready reckoner system (HW Community), the daily vibration exposure is determined by using the table as shown in Fig. 19.5. The exposure point system is a guide to measure the suitable daily vibration exposure from the jigsaw to the operator's hand.

## 19.6 Discussion

Figure 19.6 shows the vibration pattern for blades T144D and T345XF. The graph indicates that the thickness of the silicone has a direct effect on the vibration pattern. The vibration decreases steadily from 2 to 8 mm thickness but increases significantly during 10 mm thickness. The pattern for blade T111C, however, has marginally fluctuated, but increases slightly at 10 mm thickness.

As shown in Fig. 19.6, the application of silicone rubber as a method to reduce the hand-arm vibration proofs to be a good solution. The vibration value for each

| Vibration Magnitude m/s² | 5 min | 15 min | 30 min | 1 h | 1 h 30 min | 2 h | 3 h | 4 h | 5 h | 6 h |
|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 265 | 600 | | | | | | | | |
| 30 | 150 | 450 | 900 | | | | | | | |
| 25 | 105 | 315 | 625 | 1250 | | | | | | |
| 20 | 67 | 200 | 400 | 800 | 1200 | | | | | |
| 19 | 60 | 180 | 360 | 720 | 1100 | 1450 | | | | |
| 18 | 54 | 160 | 325 | 650 | 970 | 1300 | | | | |
| 17 | 48 | 145 | 290 | 580 | 865 | 1150 | | | | |
| 16 | 43 | 130 | 255 | 210 | 770 | 1000 | | | | |
| 15 | 38 | 115 | 225 | 450 | 675 | 900 | 1350 | | | |
| 14 | 33 | 98 | 195 | 390 | 590 | 785 | 1200 | | | |
| 13 | 28 | 85 | 170 | 340 | 505 | 675 | 1000 | 1350 | | |
| 12 | 24 | 72 | 145 | 290 | 430 | 575 | 865 | 1150 | 1450 | |
| 11 | 20 | 81 | 120 | 240 | 365 | 485 | 725 | 970 | 1200 | 1450 |
| 10 | 17 | 50 | 100 | 200 | 300 | 400 | 600 | 800 | 1000 | 1200 |
| 9 | 14 | 41 | 81 | 160 | 245 | 325 | 485 | 650 | 810 | 970 |
| 8 | 11 | 32 | 64 | 130 | 190 | 255 | 385 | 500 | 640 | 770 |
| 7 | 8 | 25 | 49 | 98 | 145 | 195 | 295 | 390 | 490 | 590 |
| 6 | 6 | 18 | 38 | 72 | 110 | 145 | 215 | 290 | 360 | 430 |
| 5.5 | 5 | 15 | 31 | 61 | 91 | 120 | 100 | 240 | 305 | 385 |
| 5 | 4 | 15 | 25 | 50 | 70 | 100 | 150 | 200 | 250 | 300 |
| 4.5 | 3 | 10 | 21 | 41 | 61 | 81 | 120 | 160 | 205 | 245 |
| 4 | 3 | 8 | 16 | 32 | 48 | 64 | 95 | 130 | 160 | 190 |
| 3.5 | 2 | 6 | 13 | 25 | 37 | 49 | 74 | 98 | 125 | 145 |
| 3 | 2 | 5 | 9 | 15 | 27 | 36 | 56 | 72 | 90 | 110 |
| 2.5 | 1 | 3 | 6 | 13 | 19 | 25 | 38 | 50 | 63 | 75 |
| 2 | 1 | 2 | 4 | 8 | 12 | 18 | 24 | 32 | 40 | 48 |
| 1.5 | 0 | 1 | 2 | 5 | 7 | 9 | 14 | 18 | 23 | 27 |
| 1 | 0 | 1 | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |

Exposure time T

Above exposure limit value
Likely to be at or above limit value
Above exposure action value
Likely to be at or above action value
Below exposure action value

**Fig. 19.5** Ready reckoner table (HAV exposure points system ready reckoner note—points formulas)

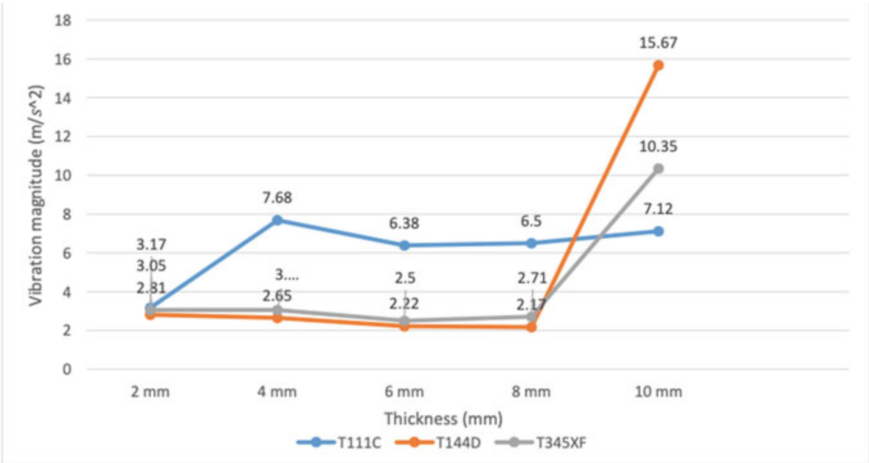


**Fig. 19.6** Effects of the dampening thickness toward vibration magnitude

blade decreases as the thickness of the silicone rubber increases. The efficiency of the silicone rubber, however, shows a different result for blade T111C. It shows an inconsistent graph pattern and produces greater vibration compared to the other types of blade.

**Fig. 19.7** Inner condition of the dampening glove with silicone rubber

T111C blade understandably provides the best result since it is the official blade as it is the default blade offered by the manufacturer together with the machine. The machine is believed to be optimized according to the T111C blade. The implementation of silicone rubber as a dampener to the machine-blade combination has disrupted the balance resulting to an increase in vibrations in cutting process. Although the vibration decreases after 4 mm, it begins to increase when thickness is approaching 10 mm.

A similar pattern is recorded when the dampener thickness reaches 10 mm. The vibration magnitude increases for all types of blades. This is due to excessive force used by the operator to hold the jigsaw handle to maintain the position during the cutting process as the thickness becomes thicker. In terms of ergonomic, at 10 mm thickness, the operator experiences discomfort due to a thick layer of the silicone rubber used on the glove for dampening purpose. Figure 19.7 shows the position of the silicone dampener in the hand glove.

It can be concluded that the thickness of the silicone rubber between 2 and 8 mm is the optimum thickness of the silicone rubber that can reduce hand-arm vibration exposure. The score point on the exposure point system is mostly falling below than exposure action value (EAV) which is in the green zone and below 4.5 m/s$^2$ or 120 points, especially for blades T144D and T345XF. Compared to the previous test with no silicone rubber used as vibration dampening, the vibration magnitude produced for all types of blades was higher, and they are above the EAV, which is in the yellow zone. However, these exposures must not be assumed to be safe. There may be a risk of HAVS in some workers, especially after many years of exposure.

## 19.7 Conclusion

This experiment answers questions about hand-arm vibration exposure on a jigsaw machine during operation. Excessive jigsaw machine vibration can cause a disorder known as hand-arm vibration syndrome (HAVS), which has both vascular and neurological components. It is most common in industrial power tools, where the cost of cutting can be reduced simply by using the right blades for the job. If workers decided to use a coarse blade for faster operation, more research is needed to determine the best approach.

This experiment found that a silicone rubber dampener is only effective between 2 and 8 mm. The dampener's efficiency will be greatly reduced if it is thicker than 8 mm. The operator's unsteady feeling caused by the thicker dampener has resulted in a natural reaction of a firmer hand grip during the cutting process, increasing the vibration exerted by the machine on the hand. Hand-arm vibration syndrome (HAVS), which has both vascular and neurological components, can be caused by excessive jigsaw machine vibration. It is most frequent in industrial power tools, where the vibration of the cutting process can be minimized simply by using a silicone rubber dampener.

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