HAND ARM VIBRATION AND PERSONAL NOISE EXPOSURE CHARACTERISTICS OF HAND HELD GRASS CUTTER MACHINES

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The objective of this study was to acquire and evaluate the hand arm vibration and personal noise exposure characteristics of hand held grass cutter machine during their normal operation time. On-site measurement included five types of hand held grass cutter machines. In this study, the hand arm vibration and personal noise exposure level of different machine were measured at practical cutting condition in accordance to noise exposure regulation and guidelines on occupational vibration which complies with Malaysia Occupational Safety and Health Act (OSHA), 1994. The hand arm vibration level on the both workers right and left handle of the grass cutter machine were measured and analyzed, respectively. The personal noise exposure was measured using dosimeter closed as an earring zone of the workers. The vibration frequency weighting acceleration was calculated by using h-weighting while A-weighting for noise exposure. The hand arm vibration acceleration value was expressed in the root-mean-square (rms) combination of all three major axis ($a_{hwx}$, $a_{hwy}$ & $a_{hwz}$). The estimated daily vibration exposure, $A(8)$ were differ between 2.1 to 20.7 ms$^{-2}$ for right hand while 2.7 to 29.1 ms$^{-2}$ for left hand. The estimated equivalent sound levels of the grass cutter machine were measured between 70.5 to 101.1 dB(A) and the estimated dose value calculated between 6.7 to 460.1% in the normal grass cutting operations. In short, workers will induce fingers blanching in 10% of the exposed person after less than 3.7 years exposed to hand arm vibration.

1. Introduction

The model of hand held grass cutter machine is widely applied in various tropical countries for maintenance of grass areas landscape. A typical public open grass compound needs monthly grass cutting operation either in highway or facilities location. It produce a service industry with large numbers of workers involved using the hand held grass cutter to maintain grass growth. The workers involved in these duties are generally contract workers with less awareness related on occupational safety and health such as hand arm vibration syndrome and noise induce hearing loss. Statistics of occupational accidents by sector, which caused death, permanent disability and non-permanent disability, have been widely investigated and represented a significant problem to the Malaysian industry. Hand held grass cutter workers were investigated under the agricultural sector which reported the second highest caused to non permanent disability behind industrial sector. In depth, there are 161 compensation claims under musculoskeletal disorder and 153 compensation claim under hearing loss case due to noise in year 2009. In spite of the facts, health surveillance in
vibration and noise was sustained. However, there is lack of effective management of agriculture service activities suggesting for worker shift scheduling by following either regulation or guideline proposed by Department of Occupational Safety and Health (DOSH), Malaysia.

Hand held vibrating tools are used in various works and induced to hand arm vibration may cause various signs, including neurological and vascular disturbances as well as muscle and joint disorder\(^6\). These are commonly known as hand arm vibration syndrome (HAVS). Symptoms of HAVS are numbness, tingling, loss of grip strength force and incapacity of work process. Prolonged vibration transmitted to hand caused vibration induce white fingers or finger blanching due to poor blood supply. On the other side, sound produce by vibrating equipment will also produce unwanted sound which associated with noise induce hearing loss (NIHL)\(^3\). The severity of hand arm vibration and noise exposure are based on the total magnitude, \(m/s^2\) of vibration produce by the machine and duration of routine operation.

This work shares the findings from onsite hand arm vibration and personal noise measurement study of a five different hand held grass cutter machine which normally used by workers in agriculture sector. The objective of this study was to acquired and evaluates the hand arm vibration and personal noise exposure characteristics of hand held grass cutter machine according to establish safety standard, regulation and guidelines.

2. Regulation and guidelines concerning hand arm vibration and noise

The DOSH Malaysia establishes the minimum health and safety requirements regarding the occupational vibration of workers involved in vibrating tools, and states that the vibration transmitted to the hand arm system is to be measured in accordance with the International Standard\(^8\). Furthermore, American Conference of Governmental Industrial Hygienists (ACGIH) specifies the threshold limit value and duration of exposure to be followed for the purpose of mitigating HAVS\(^9\). Besides that, European Directive established the regulation to protect worker from vibration hazard\(^10\). Although, there are several detail safety description related on human response to vibration, it indicated that hand arm vibration disease reduce after implementing the Directive 2002/44/EC in Great Britain\(^11\).

To protect workers from developing NIHL in Malaysia, a clear fact under factories and machinery (noise exposure) regulation have been proposed since 1989\(^12\). In Europe, European Union (EU) adopted the Noise Directive\(^13\) on February 6, 2003. This directive establishes guidelines with respect to personal noise exposure that recommended limit and action values for occupational exposure to noise.

For hand arm vibration assessment, articles 3 of Directive 2002/44/EC establish the following safety limits for A(8):

- Exposure limit value (ELV) = 5 m/s\(^2\)
- Exposure action value (EAV) = 2.5 m/s\(^2\)

The ELV is the maximum amount of hand arm vibration worker may be exposed to in any single day. It indicates a potential high risk above which workers should not be exposed. The EAV is the daily amount of hand arm vibration exposure which employers are required to take acceptable and suitable control measure to mitigate exposure or to provide periodically health surveillances for the workers involved. In Malaysia, Appendix B of guidelines on occupational vibration\(^14\) was used as reference in worker involved in hand arm vibration. In this particular guidelines, established threshold limit value (TLV) and exposure duration for vibration transmitted to hand arm in A(8):

- 4 hours and less than 8 hours = 4 m/s\(^2\)
- 2 hours and less than 4 hours = 6 m/s\(^2\)
- 1 hours and less than 2 hours = 8 m/s\(^2\)
- Less than 1 hour = 12 m/s\(^2\)

The TLV is vibration acceleration component levels and the duration of exposure for hand arm vibration. The values shall be used as a basis for the control measure of hand arm vibration exposure.

For noise assessment, articles 3 of Directive 2003/10/EC establishes the following personal action and limit values in respect of the daily noise for \(L_{eq}\):
• Exposure limit value (ELV); $L_{eq} = 87 \text{ dB(A)}$
• Upper exposure action values (EAV$_{up}$); $L_{eq} = 85 \text{ dB(A)}$
• Lower exposure action value (EAV$_{lo}$); $L_{eq} = 80 \text{ dB(A)}$

Factories and machinery (noise exposure) regulation 1989 was used by Malaysia government to protect worker from hearing impairment. This regulation establishes the permissible exposure limit for $L_{eq}$:

• Permissible exposure limit (PEL); $L_{eq} = 90 \text{ dB(A)}$ or daily noise dose equal to 100%
• Maximum exposure limit (MEL); $L_{eq} = 115 \text{ dB(A)}$
• Action level; $L_{eq} = 85 \text{ dB(A)}$ or daily noise dose equal to 50%

The workers need to undergo audiometric test to determine whether their work activity induced to permanent or temporary threshold shift which able to induce hearing loss. It is a duty to employer to provide or supplement controls with approved hearing protection device such as ear plug.

3. Material and method

This work was part of a much wider research (168 workers comes from maintenance grass and turf operation personal company) conducted to gather data relating 5 different types of hand held grass cutter machine hazard, such as hand arm vibration, health and noise. Each worker was interview about the machine he usually works with and the hand arm vibration and noise exposure was also measured while performing their routine task. Hand arm vibration measurement was performed for the both handle per machine and noise exposure. The orientation of the vibration measurement following the biodynamic and basicentric coordinate system for the hand by using tri-axial accelerometer propose in ISO 5349. The microphone of dosimeter was placed as closed to worker hearing zone. The frequency of each type of hand held grass cutter machine for which hand arm vibration and noise measurement were carried out can be seen in Table 1, as well as the mean height, mean weight and mean working experience for each machine. Five different types of hand held grass cutter machine were identified. The technical specifications of these machines are given in Table 2. The hand held grass cutter machines were different in structural component design and grip handle as well. However, the same engine model that generate power (source of vibration and noise) for cutting purpose make the best indication to differ the type of machine used by hand held grass cutter workers.

### Table 1. Frequency, mean height, mean weight and mean working experience of hand held grass cutter workers participated in the survey for each type of grass cutter machine

<table>
<thead>
<tr>
<th>Hand held grass cutter workers</th>
<th>Frequency</th>
<th>Mean Height (m)</th>
<th>Mean Weight (kg)</th>
<th>Mean Working Experience (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>47</td>
<td>1.62 ± 0.13</td>
<td>60.35 ± 20.10</td>
<td>44</td>
</tr>
<tr>
<td>Type B</td>
<td>49</td>
<td>1.62 ± 0.15</td>
<td>60.13 ± 25.75</td>
<td>40</td>
</tr>
<tr>
<td>Type C</td>
<td>23</td>
<td>1.64 ± 0.13</td>
<td>57.86 ± 13.90</td>
<td>32</td>
</tr>
<tr>
<td>Type D</td>
<td>23</td>
<td>1.67 ± 0.13</td>
<td>65.50 ± 21.45</td>
<td>19</td>
</tr>
<tr>
<td>Type E</td>
<td>26</td>
<td>1.55 ± 0.14</td>
<td>57.97 ± 16.45</td>
<td>35</td>
</tr>
</tbody>
</table>

### Table 2. The technical specification of the survey hand held grass cutter machines

<table>
<thead>
<tr>
<th>Specification</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Type D</th>
<th>Type E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>TU33</td>
<td>TB33 / TL33</td>
<td>KNC 3340</td>
<td>TB43</td>
<td>BG328</td>
</tr>
<tr>
<td>Discharge capacity (cc)</td>
<td>32.6</td>
<td>32.8</td>
<td>33</td>
<td>43</td>
<td>30.5 – 32.8</td>
</tr>
<tr>
<td>Net weight (kg)</td>
<td>9</td>
<td>9.5 – 9.8</td>
<td>9.7</td>
<td>8 – 9.4</td>
<td>7.8 – 10.5</td>
</tr>
<tr>
<td>Standard power (kW)</td>
<td>0.97</td>
<td>0.9</td>
<td>1.26</td>
<td>1.25 – 1.57</td>
<td>0.81 – 0.85</td>
</tr>
<tr>
<td>Max output (rpm)</td>
<td>6500</td>
<td>6500</td>
<td>6500</td>
<td>7000</td>
<td>6000 – 7500</td>
</tr>
</tbody>
</table>
The analysis of hand arm vibration exposure in compliance with ISO 5439 is based on vibration quantity that combines all three axes. This hand arm vibration total value, \( a_{hv} \), was defined as the root mean square or equivalent vibration transmitted to hand of three axes values shall be obtained by using Equation (1).

\[
a_{eq} = a_{hv} = \sqrt{a_{hx}^2 + a_{hy}^2 + a_{hz}^2}. \tag{1}
\]

where; \( a_{hx}, a_{hy} \) and \( a_{hz} \) are the frequency of hand arm vibration measurement proposed in ISO 5439 (h-weighted) acceleration values for each of axis which contain of amplitude and time exposure. The hand arm vibration exposure depends on the magnitude of the total value of vibration and the duration of exposure. Daily vibration duration is the total time which the hands are exposed to vibration during a working day. It is very important to estimates the total daily vibration exposure since hand held grass cutter workers not operating the machine in 8 hours per day. An average time of workers operating the machine is about 5.46 hours per day. According to ISO 5439, the daily vibration exposure shall be stated in term of the 8 hours energy equivalent frequency h-weighted vibration total values as \( A(8) \). The daily vibration exposure, \( A(8) \) under normal operating condition shall be obtained using Equation (2).

\[
A(8) = a_{hv} \sqrt{\frac{T}{T_0}}. \tag{2}
\]

where; \( a_{hv} \) is the vibration total value for the hand held grass cutter machine, \( T \) is the duration of operating the machine and \( T_0 \) is the reference time (8 hours). From the measured \( A(8) \) values, the maximum daily usage time of the hand held grass cutter will be known and then used to determine the extent of compliance with the regulation or guidelines. Equation (3) was used to estimate 10% of hand held grass cutter workers are exposed to a risk of changes fingers colour so call vibration-induce white finger.

\[
D_y = 3.18(A(8))^{-1.06}. \tag{3}
\]

where; \( A(8) \) is the daily vibration exposure (m/s²), \( D_y \) is the group mean of exposure time of hand arm vibration (year).

NIHL is a result of sound level and duration of exposure. The evaluation of personal noise exposure in compliance with factories and machinery (noise exposure) regulation 1989 is based on ISO 9612. The daily noise exposure, \( Dose \) or \( L_{eq} \) was define as the total noise exposure of worker during a working day and is derived from the Equation (4) and (5).

\[
L_{eq} = 90 + 16.61 \log_{10} \left( \frac{D}{12.5T} \right). \tag{4}
\]

\[
Dose_n = Dose \times \frac{n}{T_0}. \tag{5}
\]

where; \( D \) is the dose value produce by dosimeter (%), \( T \) is the duration of measurement (hours), \( L_{eq} \) is the sound equivalent level (dB(A)), \( n \) is the duration of actual exposure during operating machine (hours), \( T_0 \) is the duration of working hours per day (hours).

Figure 1, shows the schematic and set up of hand arm vibration and noise data collection process. Hand held grass cutter workers working as subcontractor of highway and facilities grass maintenance was selected as subject in this study. Blaze software version 6.1.1 for Larson Davis human vibration meter (HVM 100, PCB Piezotronic, 00496) was used to analyze hand arm vibration exposures following ISO 5349. Raw, h-weighted tri-axial hand arm vibration measurement were collected using ICP accelerometer mounted on the both left and right handle of hand held
grass cutter machine, respectively. The tri-axial piezoelectric accelerometer handle mounted adapter inserted between the worker’s fingers and the handle and fixed on the handle by tape. The right hand was used for operating the speed cutting control. Each handle was measured one time with sampling rate of 1 second period for 4 minutes. However, to produce the statistical significant of vibration data, at least 60 second should be enough for vibration data collection.

The noise dose meter version 2.2 for TES 1355 logging dosimeter was used to evaluate personal noise exposures following ISO 9612. The noise signal was assumed to be in steady continues state while the workers operating the machine because it is able to project the noise exposure without undergo full day noise sampling. Hence, average 10 minutes of sampling rate of 1 second per worker. Threshold level was set at 90 dB while criterion level was set at 80 dB. The sampling rate is slow and exchange rate is 5 dB. This is the standard operating procedure before taking any noise monitoring assessment establish by DOSH, Malaysia.

![Schematics of hand arm vibration and noise data collection process](image)

**Figure 1.** Schematics of hand arm vibration and noise data collection process

### 4. Results and discussion

Magnitude of vibration level depends on the operating system of the hand held grass cutter machines. The worker exposes the hand arm vibration in his hands at the left and right grip of handle. It was observed that the rms vibration acceleration values for left hand are higher compared to right hand (Fig. 2). In addition to vibration, the landscape working area such as drain and slope is the other difficulty for the workers to carry out during their routine operation activities. The $a_{yv}$ acceleration values for each measurement axes for the five different type of hand held grass cutter machine are given for left and right hand of worker in Fig. 4a and b, respectively. The $a_{bwy}$ (parallel to the longitudinal direction of handle) contribute high vibration magnitude for left hand while $a_{bwz}$ (perpendicular to the longitudinal direction of handle) contribute high vibration magnitude for right hand. The $a_{yv}$ acceleration values vary between 3.33 to 33.6 m/s² for left hand and 2.48 to 23.9 m/s² for right hand. The maximum vibration magnitude on the left hand in the y direction of machine type E was measured as 26.5 m/s². The cutting tool rotation movement of the grass cutter shaft is in the y direction. On the other side, minimum vibration magnitude values were determine as 0.93 m/s² on the left hand in the z direction of machine type C. It is the great evidence that the acceleration values of x and y direction of the left and right hand give significant contribution in increasing the total vibration value. The machine type C shows less vibration transmitted to both hand compared to other types of hand held grass cutter machine. A strong correlation is obtained between total vibration magnitude levels for both hand (Spearman correlation coefficient 0.778, $p<0.05$), and hence clear conclusion stated that the hand arm vibration of left hand were associated with vibration transmitted to right hand.
Figure 2. The rms ($a_{rms}$) acceleration values and standard deviation of hand held grass cutter machine for left and right hand in three axes.

Daily exposure value of $A(8)$ in m/s$^2$ calculated from $a_{rms}$ and the mean daily time of operation vary from 2.7 to 29.1 m/s$^2$ (mean 8.81 and S.D 5.02 m/s$^2$) for the left hand while 2.1 to 20.7 m/s$^2$ (mean 6.13 and S.D 3.01 m/s$^2$) for the right hand. A box plot graph showing spread of $A(8)$ according to the machine type is presented in Fig. 3. More detailed data, statistical data for daily vibration exposure, $A(8)$ for left and right hand by type of hand held grass cutter machine are presented in Table 3. Both left and right hand vibration measurement are exceeding the EAV value for the mean $A(8)$ for each type of machine. Control measures were not be implemented in reducing the vibration level such as handle vibration damper or anti vibration glove. The outliers or extreme value shows that the workers have high possibility expose to impulsive force due impact between dynamic rotation of cutting blade with stone, wood and etc. By referring to guidelines on occupational vibration, hand held grass cutter workers should operate the machine maximum 2 hours per daily to protect them from HAVS diseases. Thus, risks of HAVS have to be observed not only in the form of high vibration magnitude expose but with associate to the duration of operating the machine itself. As seen from Table 3, the $A(8)$ values are almost similar for all of the machines except for machine type C which show less vibration magnitude for both left and right hand. However, the $A(8)$ value is exceed the ELV for left hand and below EAV for right hand. This will be good perception for hand held grass cutter machine selection management proposed.

Figure 3. Box-plot graph showing spreads of daily exposure values $A(8)$ (for the left and right hand that gave the highest value) for each type of hand held grass cutter machine.
Table 3. Statistical data for daily vibration exposure, A(8) for left and right hand by type of hand held grass cutter machine

<table>
<thead>
<tr>
<th>Type of hand held grass cutter</th>
<th>Mean operating hours in a day</th>
<th>Left hand, A(8) (m/s²)</th>
<th>Mean (S.D)</th>
<th>Range</th>
<th>Right hand, A(8) (m/s²)</th>
<th>Mean (S.D)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.57</td>
<td>9.92 (4.92)</td>
<td>3.6 – 22.8</td>
<td></td>
<td>6.73 (3.94)</td>
<td>2.6 – 20.7</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>5.40</td>
<td>8.13 (5.27)</td>
<td>3.1 – 29.1</td>
<td></td>
<td>5.91 (2.70)</td>
<td>2.1 – 13.9</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>5.96</td>
<td>6.30 (3.34)</td>
<td>2.9 – 13.3</td>
<td></td>
<td>4.77 (2.27)</td>
<td>2.5 – 9.40</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>4.70</td>
<td>8.23 (4.60)</td>
<td>2.7 – 19.2</td>
<td></td>
<td>6.25 (2.84)</td>
<td>2.4 – 13.5</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>5.62</td>
<td>10.82 (3.94)</td>
<td>2.6 – 20.7</td>
<td></td>
<td>6.57 (1.96)</td>
<td>2.6 – 9.30</td>
<td></td>
</tr>
</tbody>
</table>

S.D, standard deviation; Range, minimum - maximum

Daily vibration exposure values were also calculated with the mean total exposure duration in years which may be expected to produce episodes of fingers blanching for each types of machine. The machine type C reveals the maximum duration for the left hand is 5.7 years while the right hand is 7.3 years. The minimum duration is 3.7 years for workers induce to left hand colour change which used machine type E.

Figure 4. Mean total (lifetime) exposure duration in years which may be expected to produce episodes of finger blanching (vibration-induce white fingers)

Personal noise exposure level in dB(A) of machine is considered higher in normal operating conditions is measured above action value. The maximum and the minimum equivalent noise pressure level were found to be at 93.42 and 89.97 dB(A) on the machine type A and B, respectively is presented in Table 4. These indicate that the dose values for all type of machine are above the PEL. Ear plug which serve as personal protective equipment is suitable for this case to avoid NIHL.

Table 4. Sound equivalent level (L_{eq}) and dose value (%) of hand held grass cutter machine during normal working condition

<table>
<thead>
<tr>
<th>Type of hand held grass cutter</th>
<th>L_{eq} (dB(A))</th>
<th>Dose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (S.D)</td>
<td>Range</td>
</tr>
<tr>
<td>A</td>
<td>93.42 (4.73)</td>
<td>84.1 – 101.0</td>
</tr>
<tr>
<td>B</td>
<td>89.97 (4.04)</td>
<td>70.5 – 96.7</td>
</tr>
<tr>
<td>C</td>
<td>92.88 (4.26)</td>
<td>87.0 – 101.0</td>
</tr>
<tr>
<td>D</td>
<td>92.57 (2.38)</td>
<td>88.7 – 96.9</td>
</tr>
<tr>
<td>E</td>
<td>90.80 (5.96)</td>
<td>79.9 – 99.6</td>
</tr>
</tbody>
</table>

S.D, standard deviation; Range, minimum - maximum
5. Conclusions

The vibration value that were measured in this study show that worker’s hands will be predicted to induce fingers blanching in 10% of the exposed person after less than 3.7 years for machine type E. Therefore, it is compulsory for employer to take responsibility in term of occupational safety and health. Employer should provide provision of such information, instruction, training and supervision as is necessary to ensure, so far as is practicable, to mitigate the hand arm vibration risk. Hence, the proper work schedule should be arranged to protect workers induce HAVS. The machine type C provides most comfort operating condition for worker when compared with type A, B, D and E machine. Therefore, machine type C could be recommended machine for grass cutting operation.

The equivalent noise pressure levels of hand held grass cutter machine are exceed the PEL regulation recommendations, and hence workers should undergo the audiometric test to identify any permanent threshold shift induce to NIHL. In future work, the prediction model of HAVS among hand held grass cutter worker will be developed based on the significant variable and symptoms.

6. Acknowledgement

The authors would like to express special thank to the Universiti Tun Hussein Onn Malaysia, PROPEL Bhd, Malaysia and NIOSH, Malaysia for their assistance support throughout this research.

REFERENCES