Investigating a power tiller handle and seat vibration on transportation mode

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Abstract: In this paper, a power tiller vibration was investigated at handle position as well as seat position of a trailer pulled by the power tiller. The experiments were conducted at five levels of engine speed, four levels of transmission gear ratio during transportation, and in three directions. Then the weighted 1/3rd octave spectrum was calculated from the narrow band vibration acceleration signals. The amount of vibration damage on operator's body and allowable exposure limits were calculated based on ISO standards. The results showed that the vibration increased with the engine speed increased for all the gear ratios and directions. The magnitude of vibration was the greatest at vertical direction in all the experiments. The vibration allowable exposure time was in the range of 2.32 - 5.7 years at the power tiller handle for the different engine speeds and gear ratios. The total equivalent vibration, A (8), at the trailer seat was in the range of 0.5 to 0.87 m/s2 and it exceeded the allowable limits for the reduced comfort boundary, fatigue-decreased boundary and exposure limit for 8 hrs day-1. So, it is necessary to reduce the vibration transmitted to the operator’s hand and body by designing and developing adequate insulating systems.

Keywords: vibration, operator, power tiller, exposure limits.

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1 Introduction

Applications of agricultural machines especially those machines that were guided entirely by hand, have caused many occupational safety and health problems for their operators. Operator of such equipment has been exposed to high levels of noise and vibration. Long time working with these machines can cause for movement disorders, damage to various organs of the human body including hearing loss, spine and gastrointestinal disorders and even neurological disorders. Continuous use of vibrating machinery can also cause various diseases affecting blood vessels, nerves, muscles and tissues attached to hands and arms. Dr. Maurice Raynaud (1862) initially recognized the symptoms of these diseases. Therefore, the disease was called Raynaud's phenomenon or white finger (Barber, 1992). Aside from these cases, the vibration reduces work efficiency and quality (Goglia et al., 2006). Economical features and user capabilities of power tillers in various conditions are factors encouraging the increasing use of the machine on farm applications and also for transporting agricultural products and human beings on rural roads (Sam and Kathirvel, 2006; Hassan-Beygi et al., 2005). In transportation mode, the power tiller operator’s is exposed to vibration transmitted to the hands through the power tiller handle, as well as vibration transmitted to the whole body through trailer seat. Single cylinder diesel engine of a power tiller does not promise a good balance. The forces acting on the piston during compression and power strokes are transmitted to crankshaft and engine block. Due to

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lack of vibration dampers between the engine and power tiller chassis, the engine forces are entered to the tractor chassis as shock and then through the chassis are transmitted to the power tiller handle as well as drawbar of a trailer mounted to it. The power tiller handle also acts like a cantilever beam so that one end is attached to the tractor chassis and free vibration of the other end is high (Salokhe et al., 1995). In order to reduce the risks of working with such machines, the regulations have been developed by international organizations to limit working hours and duration of vibration exposure. The ISO standard No. 2631 part 1 (1997) for whole body vibrations, ISO standard No. 5349 parts 1 and 2 (2001) for hand-arm vibration, and ISO standard No. 8041 (2005) for vibration measuring instrumentation are the examples.

The results of pervious research work showed that farm machinery drivers suffer from higher back pain than the other agricultural workers (Futatsuka et al., 1998). Wang et al. (2004) reported that the spinal movements caused by vibration were the main reason for these destructive injuries to the body, but the exact reasons have not been provided so far. In an investigation regarding the ergonomic conditions of an 8-hp power tiller, 200 farmers and 100 extension workers were studied. The study revealed that noise and vibration of the power tiller played an important role in damages experienced by them (Kang et al., 1988). Mehta et al. (1997) measured vibration of a 7.5-kW power tiller seat. The results showed that the vibration acceleration increases with increasing forward speed of the power tiller. The vibration Root Mean Square (RMS) values on non-plowed farm were 2 to 2.5 times that of asphalt and dirt rural roads. These researchers recommended that the vibration exposure time for the power tiller operator's should be less than 2.5 hours per day. Ahmadian et al. (2013) determined the vibration acceleration envelope curves of a power tiller on transportation mode. The results showed that the maximum vibration amplitude values at operator's arm, wrist, chest, and head positions were occurred at 16 Hz, 40 Hz, 4 Hz, and 5 Hz, respectively. Taghizadeh-Alisaraei (2007) assessed the vibrations of a 7.5-hp walking power tiller. Experiments were conducted at stationary condition and plowing operation. The vibration acceleration was measured on locations of chassis and handle of the power tiller as well as arm and chest of the driver. The results revealed that the vibration RMS values increased in all locations with increasing engine speed. It was observed that the dominant frequency of vibration in all locations were equal to engine speed (revolution per second). The vibration RMS values were decreased when transferring from the power tiller handle to the driver's chest. The research work conducted by Tewari et al. (2004) on power tillers with seat and without seat, showed that the greatest vibration RMS value was observed for the power tiller without seat (45 m $(s^{-1})^{-2}$), whereas it was 20 m $(s^{-1})^{-2}$ for the power tiller with seat. Dewangan and Tewari (2009) investigated vibration of a power tiller in transportation mode on asphalt road as well as rotary tillage in dry and submerged farm. Experiments were carried out in three forward speed of 1.11 m $(s)^{-1}$, 1.71 m $(s)^{-1}$and 2.31 m $(s)^{-1}$ in transportation mode and forward speed of 0.3 m $(s)^{-1}$, 0.45 m $(s)^{-1}$and 0.65 m $(s)^{-1}$ in rotary tillage. The results showed that the RMS value of vibration in the vertical direction was greater than the other directions for all forward speeds on transportation and rotary tillage.

Literature survey showed that there is limited published data concerning vibration characteristics of a 13-hp power tiller on transportation mode. In present study, vibration characteristics of a 13-hp power tiller is evaluated in transportation mode on asphalt rural road for various engine speeds and transmission gear ratios simultaneously at three perpendicular directions at the power tiller handle position as well as seat position of a trailer pulled by the power tiller.

2 Materials and methods

In this research work, vibration acceleration of a 13-hp power tiller (Mitsubishi CT-82) was measured at the right handle grip position as well as the seat position of a trailer to be pulled by the power tiller. The trailer was connected to power tiller by drawbar. The power tiller specifications were given in Table 1. In order to simulate practical use of the power tiller at transportation conditions, load of 9000 N was placed inside the attached trailer.

Table 1 Specifications of the power tiller

Combustion system	Internal, diesel, Indirect injection
Stroke cycle	Four-stroke
Rated power	13-hp at 2200 r m^{-1}
Air intake system	Naturally aspirated
No. of cylinder	Single, vertical
Cooling system	Water cooled
Number of speeds	Six-forward, two-reverse
Type of clutch	Dry, multi-plates
Steering	Side brake system
Tire size (pneumatic)	152.4-305 mm

Experiments were conducted at five levels of engine speed (1400 r m^{-1}, 1600 r m^{-1}, 1800 r m^{-1}, 2000 r m^{-1}, and 2200 r m^{-1}), four levels of transmission gear ratio (2-light, 3-light, 2-heavy, and 3-heavy), and at the three perpendicular directions (lateral, longitudinal and vertical) on asphalt rural road. Number of three CTC-AC192 types of accelerometers was used to measure vibration of the power tiller at handle grip and the trailer seat positions. The accelerometers were screwed on a 2×2×2 cm^3 metallic cubic and the cubic glued at the power tiller right handle grip (Figure 1a) and the trailer seat (Figure 1b). The experiments were down while the operator was seated on the trailer seat and holding the handles to control the power tiller.

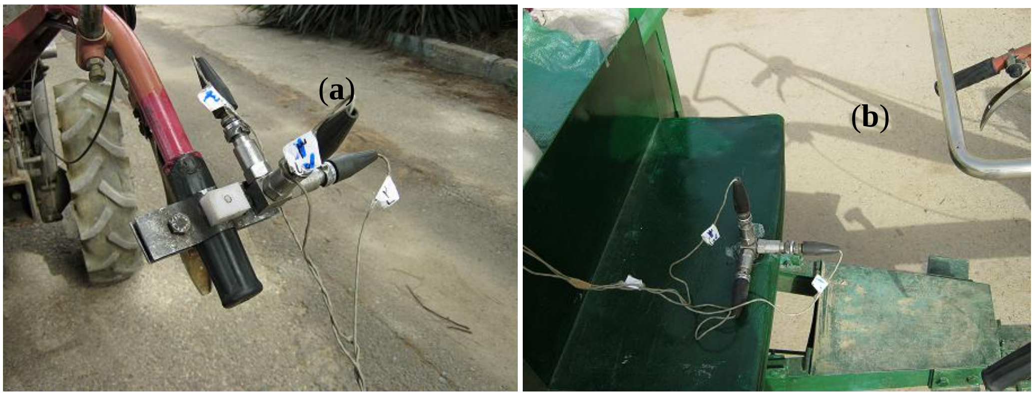

Figure 1 Mounting accelerometers: (a) the power tiller handle grip and (b) the trailer seat.

A 24-volt battery and an electronic circuit supplied the required power for this set up. Using an A/D converter, which was recognized and controlled by LABVIEW software program, the accelerometer analog output voltage was converted to digital ones with 40000 Hz sampling rate and recorded on lap-top computer hard disk. Figure 2 shows the instrumentation setup used in this study. The power tiller vibration assessment in time domain was carried out by the RMS values of vibration acceleration. The RMS was calculated by Equation 1.

$$a_{RMS} = \left[\frac{1}{T} \int_0^T a(t)^2 dt \right]^{1/2} \qquad (1)$$

Where, a_{RMS} is root mean square of vibration acceleration (m/s^2), a(t) is measured vibration acceleration amplitude (m/s^2), and T is duration of measured vibration acceleration (s).

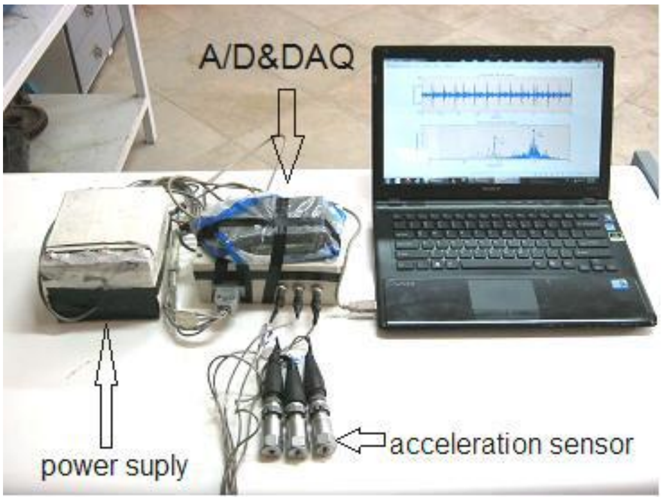

Figure 2 Vibration measurement and data acquisition set up.

For a detailed investigation of the vibration signals and evaluation of operator health, it is necessary to do the analysis of the vibration signals in frequency domain. The recorded time domain digital signals were converted to frequency domain narrow band signals by fast Fourier transform (FFT) algorithm using MATLAB software program. To overcome the sudden changes and uncertainty of the narrow band signals, the narrow band frequency domain signals were converted to 1/3rd octave frequency band signals by a subroutine computer program. The 1/3rd octave frequency spectrum was weighed in order to calculate the allowable exposure limits and compare with standard values. Then the total weighted vibration acceleration RMS values in frequency domain for HTV and WBV calculated by Equation 2 and Equation 3, respectively:

For hand transmitted vibration:

$$a_{hv} = \left[\left(a_{RMS,X}\right)^2 + \left(a_{RMS,Y}\right)^2 + \left(a_{RMS,Z}\right)^2 \right]^{1/2} \qquad (2)$$

For whole body vibration:

$$a_v = \left[\left(k_x * a_{RMS,X}\right)^2 + \left(k_y * a_{RMS,Y}\right)^2 + \left(a_{RMS,Z}\right)^2 \right]^{1/2} \qquad (3)$$

Where, a_{hv} and a_v are the root mean square of total weighted vibration acceleration (m/s^2) for HTV and WBV respectively, $a_{RMS,X}$ is the root mean square of weighted vibration acceleration in X direction (m/s^2), $a_{RMS,Y}$ is the root mean square of weighted vibration acceleration in Y direction (m/s^2), and $a_{RMS,Z}$ is the root mean square of weighted vibration acceleration in Z direction (m/s^2). k_x and k_y are multiplying factors and the exact value of the multiplying factors depends on the frequency weighing selected and according to ISO standard 2631-1, for seated persons and effects of vibration on perception and comfort k_x = ky=1. The equivalent vibration acceleration for eight hours, A(8) or $a_{v(eq.8)}$, was calculated, using Equation 4.

$$A(8) = (a_v) \times \sqrt{\frac{t}{T(8)}} \qquad (4)$$

Where, t is the time that the body expose to the vibration in a working day (s), T(8) is reference time (eight hours, s), and A(8) is the equivalent vibration acceleration for eight hours working per day (m/s^2).

The amount of vibration damage on operator's body and the exposure limits were calculated in accordance with the ISO standard No. 2631 (1997) by comparing the weighted 1/3rd octave acceleration signals with the ISO diagrams. Same as for WBV, A(8) was calculated for HTV using Equation 4 and replacing a_v with a_{hv}, then the vibration exposure time for the operator's hand-arm was calculated using Equation 5 according to the ISO standard No. 5349 (2001).

$$\frac{D_y}{\text{year}} = 31.8\left(\frac{A(8)}{m/s^2}\right)^{-1.06} \qquad (5)$$

Where, D_y is time after which in 10% of operators exposed to the amount of hand-arm weighted vibration, A(8), various diseases and disorders, and depreciation on their fingers may occur (year).

3 Results and discussion

3.1 The time domain vibration acceleration signals

The time domain vibration acceleration signals on vertical direction for the engine speed of 2200 rpm and 3-light gear ratio at the trailer seat and power tiller handle positions are shown in Figure 3a & 3b, respectively. As depicted from parts of this Fig., the maximum peak amplitude at the trailer seat and tractor handle positions were ±10 m/s^2 and ±45 m/s^2, respectively. It is clear that reduction of vibration energy in transmission path from the power tiller engine to the trailer seat is more than that of the power tiller engine to the handle; therefore, the maximum peak amplitude at the seat position was lower than the handle position.

Figure 4 shows the RMS values of total vibration acceleration (sum of the three x, y, and z directions) in time domain for the different engine speeds and gear ratios at the power tiller handle position. The total acceleration RMS values were in the range of 14-26 m/s^2 for the various engine speeds and gear ratios. The vibration RMS values increased for all the gear ratios when the engine speed is increased from 1400 r m^{-1}to 2000 r m^{-1}. The handle of power tiller acts like a cantilever beam (Salokhe et al., 1995). With increasing the engine speed, number of combustion strokes and the piston blows per the unit time were increased. Therefore, vibration at the base of the handle that was attached to the power tiller chassis is increased, consequently the vibration at the free end of the handle is also increased.

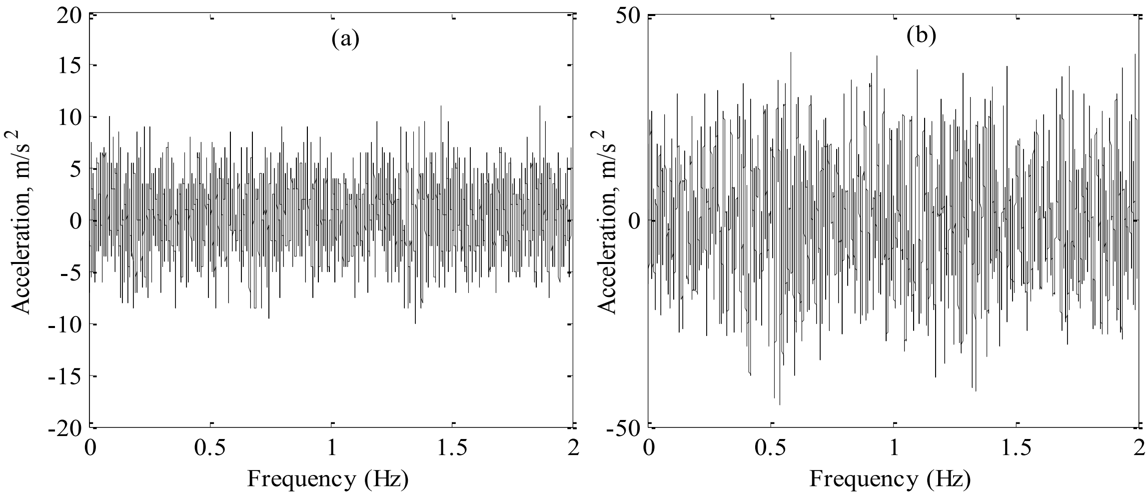

Figure 3 The time domain vibration acceleration signals on vertical direction for the engine speed of 2200 r m^{-1} and 3-light gear ratio at: (a) the trailer seat and (b) the handle positions.

This trend is confirmed by the other researchers for similar investigations (Sam and Kathirvel, 2006; Salokhe et al., 1995; Taghizadeh-Alisaraei, 2007). However, the increasing trend is not observed at 2200 r m^{-1} engine speed because this speed is the rated engine speed. At this engine speed, the engine and its components are dynamically balanced. The maximum and minimum increases in vibration acceleration are observed for 2-light and 3-light gear ratios, respectively when the engine speed ranges from 1400 r m^{-1}to 2200 r m^{-1}.

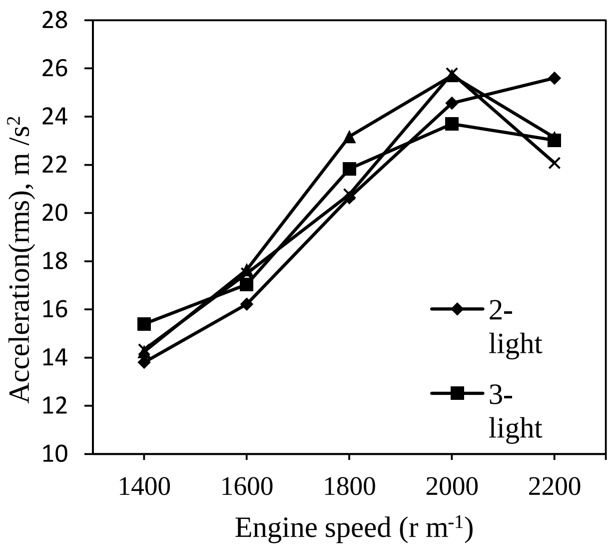

Figure 4 The effect of engine speed on the RMS values of total vibration acceleration for the different gear ratios at the handle position.

Variations of the total vibration acceleration RMS values versus the engine speed at the trailer seat position in time domain are shown in Figure 5 for the different engine speeds and gear ratios. The total acceleration RMS values were in the range of 2.8 m/s^2- 4.8 m/s^2 for the different engine speeds and gear ratios. With increasing engine speed, the vibration RMS values at the trailer seat position are increased for all the gear ratios. The reason for this increasing trend might be attributed to increasing number of combustion strokes and the piston blows per unit time. Of course, the vibration RMS increase at this position is lower than the handle position that could be as a result of dissipation of vibration energy and structural damping. The maximum and minimum increase in vibration acceleration is observed for 2-heavy and 3-heavy gear ratios, respectively when the engine speed is increased in range of 1400-2200 rpm. The variations of vibration acceleration in the different gear ratios for the engine speeds of 1400, 1600 r m^{-1}, 1800 r m^{-1}, 2000 r m^{-1}and 2200 r m^{-1} were about 0.5 m/s^2, 0.7 m/s^2, 0.9 m/s^2, 1.1 m/s^2, and 1.3 m/s^2, respectively. The reason for these variations might be attributed to the trailer oscillations due to changing forward speeds or in other words, the effects of road unevenness.

Investigation of vibration signals in time domain for all of the experiments revealed that the vibration accelerations values RMS for the vertical direction were greater than the lateral and longitudinal directions, which could be attributed to piston impact of the power tiller diesel engine at Top Dead Center (TDC) .

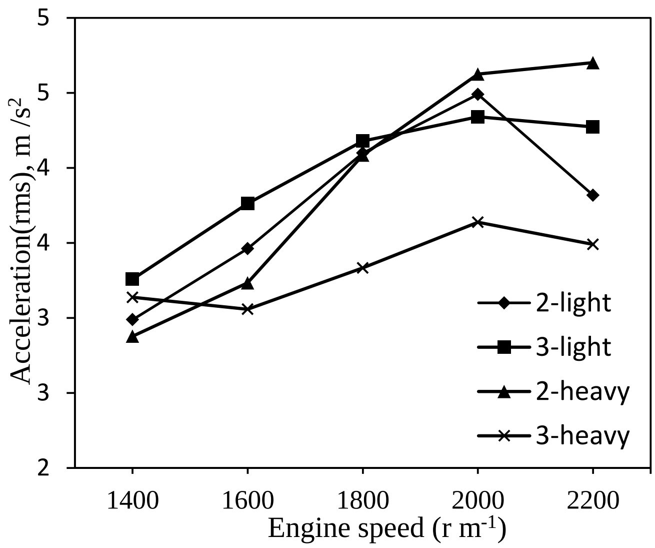

Figure 5 The effect of engine speed on the RMS values of total vibration acceleration for the different gear ratios at the trailer seat.

3.2 The frequency domain vibration acceleration signals

Figure 6 shows the narrow band frequency spectrum of vibration acceleration on vertical position for the trailer seat and power tiller handle positions at 2200 r m^{-1} engine speed and 3-light gear ratio. The maximum amplitude peaks at the trailer seat and handle positions reached to 1.5 m/s^2 and 10 m/s^2, respectively. Structural damping and reduction of vibration energy in transmission path might be responsible for peak amplitude reduction. At the handle position, the vibration acceleration amplitudes are damped strongly at frequencies greater than 200 Hz. The acceleration value at the handle position was very high in certain frequencies, which was due to free vibration of the power tiller handle. This phenomenon is also confirmed for a 7.5-hp power tiller vibration (Taghizadeh-Alisaraei, 2007). At the handle position, the maximum amplitude peak is occurred at 36.7 Hz which is related to rotational speed of the engine i.e. 2200 r m^{-1}.

Due to un-smoothed nature of narrow band frequency spectra, comparing the data for different conditions is not so easy. Therefore, in order to explain the results and to calculate the vibration allowable exposure limits and compare with standard values, the smoother 1/3rd octave vibration frequency band is selected.

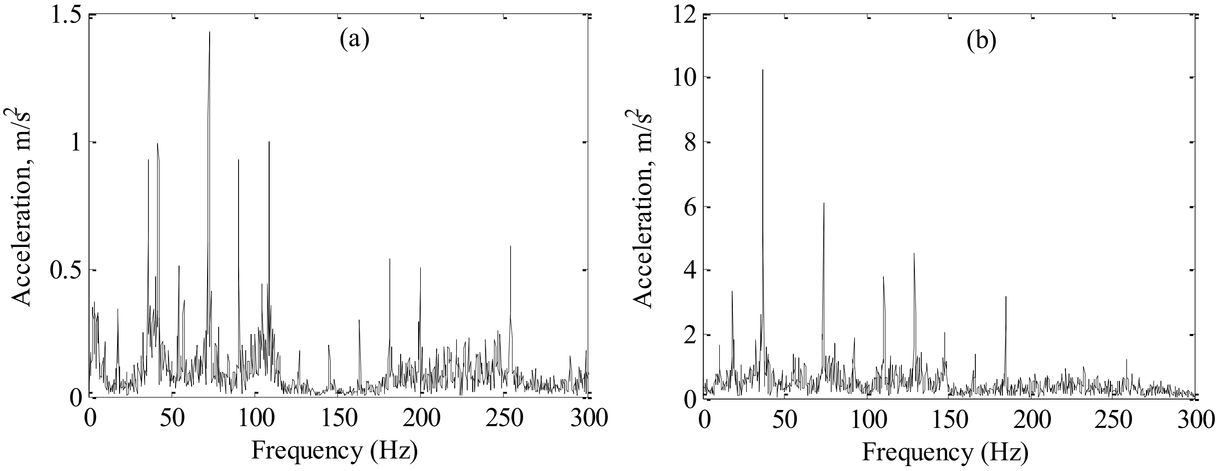

Figure 6 The narrow band frequency domain vibration acceleration signals on vertical direction for 2200 rm^{-1} engine speed and 3-light gear ratio at: (a) the trailer seat and (b) the handle positions.

3.2.1 The 1/3rd octave spectrum of vibration acceleration at the tractor handle position

Figure 7 shows the effect of engine speed on 1/3rd octave total weighted vibration acceleration (sum of the three directions x, y and z) at the handle position for the different gear ratios. Different parts of this Figure showed that at frequencies more than 100 Hz, the vibration acceleration was less than 1 m/s^2. However, at frequencies less than 100 Hz, the total weighted acceleration did not show uniform variations for the different engine speeds and gear ratios. As illustrated in Figure 7, the vibration acceleration amplitude has some peaks at center frequencies of 12.5, 16, 20, 25, 31.5, and 40 Hz for the different gear ratios. The peaks observed at center frequency of 25, 31.5, and 40 Hz

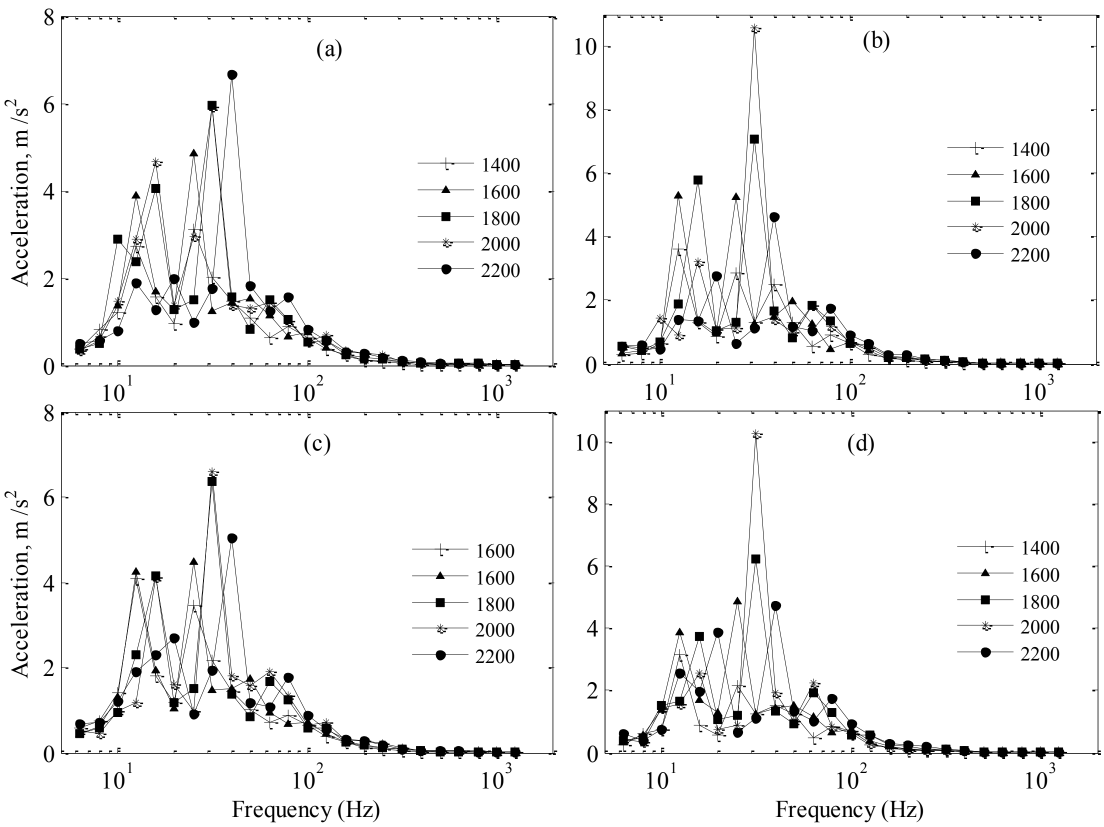

Figure 7 1/3rd octave frequency band of total weighted acceleration for the different engine speeds at the handle position for gear ratios of: (a) 2-light, (b) 3-heavy, (c) 3-light, and (d) 2-heavy.

could be related to 1400 r m^{-1}and 1600 r m^{-1}, 1800 r m^{-1} to 2000 r m^{-1}, and 2200 r m^{-1} engine speed, respectively. The peaks at center frequencies of 12.5, 16 and 20 Hz could be related to the combustion process frequency and frequency of engine components including camshaft and injection pump, which had one half speed of the engine crankshaft. As depicted from this Figure, the greatest peak of vibration acceleration is observed in frequency of 31.5 Hz for all the gear ratios except 2-light. The maximum amplitude for 2-light gear ratio is observed at 40 Hz, which could be due to handle resonance. The maximum peak (11 m/s2) at the frequency of 31.5 Hz is related to 2000 rpm engine speed and 3-heavy gear ratio. According to Figure 7, the amplitude of total vibration acceleration in the frequency range of 10 to 80 Hz is greater than the allowable vibration exposure limit (2m/s^2) for hand-arm. Investigation of Sam and Kathirvel (2006) on a 7.5-hp power tiller at handle position and transportation mode with an empty trailer showed that the measured vibration was more than that of the hand-arm allowable vibration exposure limit.

3.2.2 The allowable exposure time for operator's hand-Arm

The equivalent vibration acceleration for eight hours, A(8), at the power tiller handle position for the different gear ratios and engine speeds is shown in Figure 8. The equivalent acceleration was increased with increasing the engine speed from 1400 to 2000 r m^{-1} for all the gear ratios at the handle position. The equivalent acceleration was reduced with further increase in the engine speed to 2200 r m^{-1}. The increasing trend of equivalent acceleration with the engine speed is due to increase in combustion cycles per unit time and increase in dynamic forces of crank-piston mechanism with engine speed. However, this trend was not observed at 2200 r m^{-1} engine speed because the 2200 r m^{-1} engine speed was the rated speed of the power tiller engine and at this speed, the engine and its components are dynamically more balanced. The equivalent acceleration values in 2-heavy gear ratio at the engine speeds of 1600 r m^{-1}, 1800 r m^{-1} and 2000 r m^{-1} are more than the other gear ratios. It seems that at the 2-heavy gear ratio, the vibration generated at the power tiller gearbox caused for resonance in the handle.

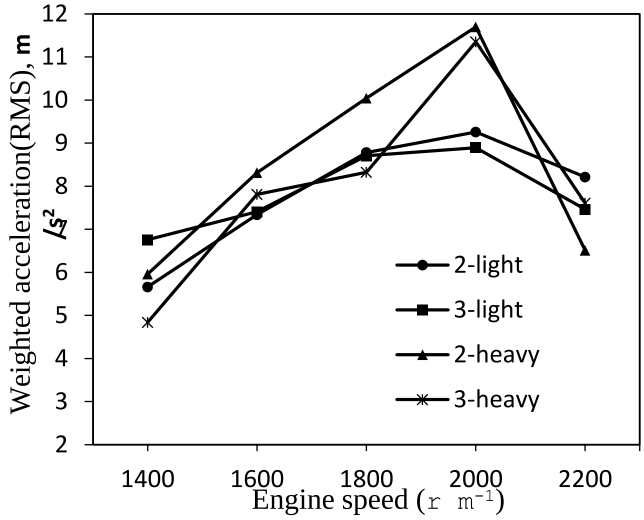

Figure 8 The effect of engine speed on the equivalent vibration acceleration, A(8), for the different gear ratios at the handle position.

Figure 9 shows the vibration allowable exposure time of the power tiller operator's hand-arm versus engine speed for the different gear ratios. The allowable exposure time was in range of 2.32 to 5.7 years for the different engine speeds and gear ratios. The allowable exposure time decreased for all the gear ratios when the engine speed was increased from 1400 r m^{-1}to 2000 r m^{-1}. The allowable exposure time was increased at 2200 r m^{-1} engine speed for all the gear ratios, which could be related to more dynamic balance of the engine at the rated speed. The Figure illustrated that after 2.32 years (at 2000 r m^{-1} engine speed and 2-heavy gear ratio) in 10% of the operators' exposed to the power tiller handle vibration the finger worn could be expected. It was reported that the vibration allowable exposure time of power tillers decreased with increasing the engine speed and travel speed. The allowable exposure time is reported in the range of 1.2 years for walking power tiller at tillage operation to 12 years for power tiller during pulling an empty trailer (Sam and Kathirvel, 2006; Taghizadeh-Alisaraei, 2007; Tewari et al., 2004).

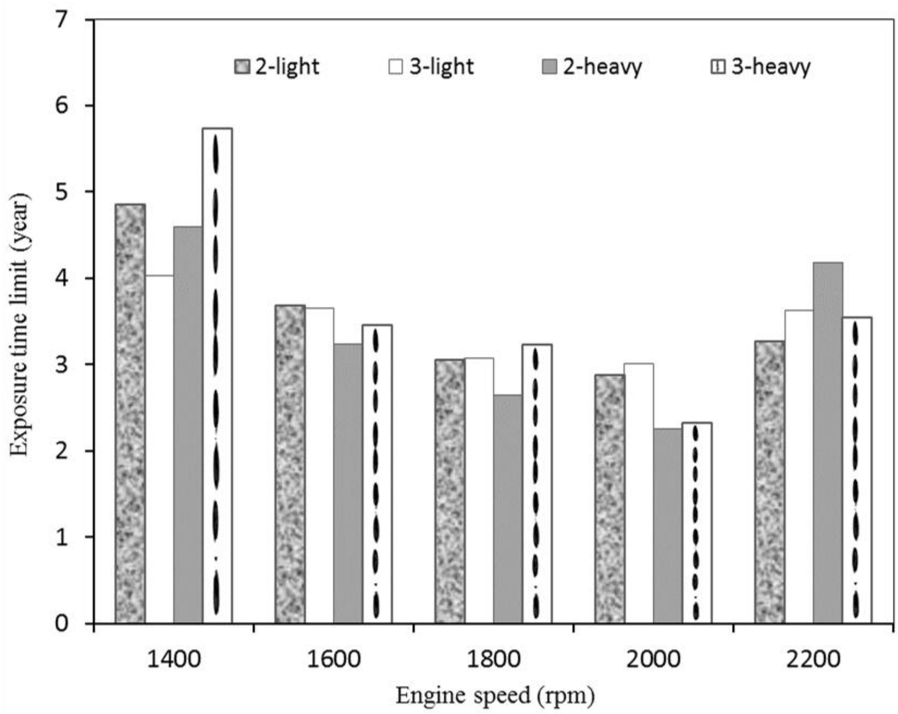

Figure 9 The effect of engine speed on the vibration allowable exposure time of the power tiller operator's hand-arm for the different gear ratios.

3.2.3 The 1/3rd octave spectrum of vibration acceleration at the trailer seat position

The effect of engine speed on 1/3rd octave total weighted vibration acceleration (sum of the three directions x, y and z) at the trailer seat position for the different gear ratios is shown in Figure 10. Investigation of the 1/3rd octave spectra showed that the vibration amplitude was not considerable for frequencies more than 100 Hz for all the gear ratios and engine speeds. Meanwhile, the human body is sensitive to frequency range of 1 to 80 Hz (ISO 2631, 1997). Therefore, the Figure 10 was drawn in the frequency range of 1 to 100 Hz. Different parts of Figure 10 depicted that the total weighted vibration acceleration had some peaks at frequencies smaller than 10 Hz, which could be attributed to the ground effects. At frequencies smaller than 10 Hz, the investigations showed that the number of frequencies at which the vibration amplitude exceeded 0.2 m/s^2 for 3-light gear ratio were more than the other gear ratios (Figure 10c), which could be attributed to more oscillation of the trailer seat due to faster forward speed of the trailer at this gear ratio. At frequencies greater than 20 Hz, the total weighted vibration acceleration had some peaks at center frequencies of 25, 31.5, and 40 Hz, that is attributed to the engine rotational speed. The maximum peak observed at center frequency of 31.5 Hz for all the gear ratios, which could be related to 1800 and 2000 r m^{-1} engine speeds. The maximum vibration amplitude is observed for 2-heavy gear ratio at frequency of 31.5 Hz with amplitude of 0.69 m/s^2 (Figure 10b). The vibration acceleration for frequency range of 25-40 Hz had amplitude greater than that of 0.3 m/s^2 for all the gear ratios, which was in the range of a little uncomfortable (ISO standard No. 2631, 1997). The vibration for 2-heavy gear ratio had amplitude greater than of 0.5 m/s^2 for frequency range of 25-40 Hz that was in the range of almost uncomfortable (ISO standard No. 2631, 1997).

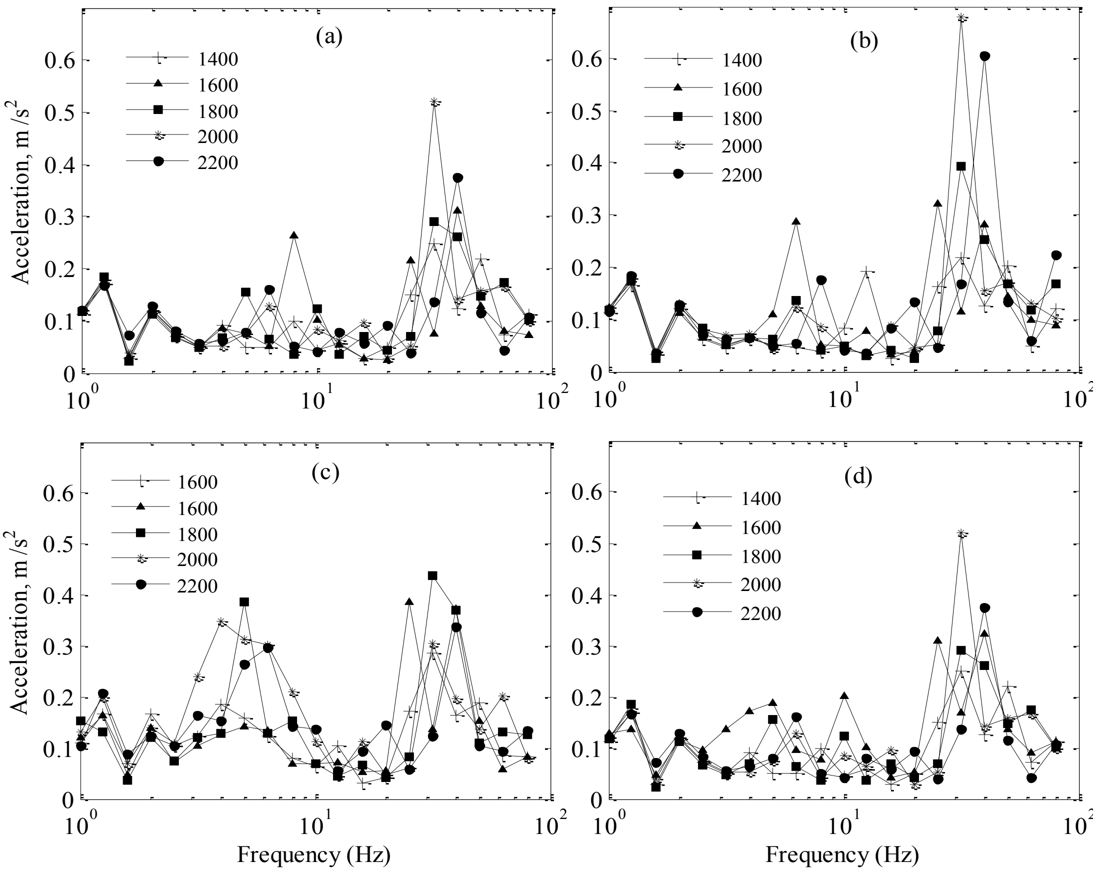

Figure 10 1/3rd octave frequency band of total weighted acceleration for the different engine speeds at the trailer seat position for gear ratios of: (a) 3-heavy, (b) 2-heavy, (c) 3-light, and (d) 2-light.

3.2.4 The allowable exposure time for operator's whole body

The total equivalent vibration acceleration for eight hours, A(8), at the trailer seat position for the different gear ratios and engine speeds is shown in Figure 11. The total equivalent vibration was in the range of 0.5 m/s^2 to 0.87 m/s^2. The seat equivalent acceleration is increased with increasing the engine speed from 1400 to 2000 r m^{-1}, although with further engine speed to 2200 r m^{-1} the equivalent acceleration is reduced for all the gear ratios. Reducing the equivalent acceleration at 2200 r m^{-1} engine speed could be attributed to the rated speed of the power tiller engine. The seat equivalent acceleration at 3-light gear ratio was the maximum value for all the engine speed levels except for 2200 r m^{-1} that could be caused by an increase in the power tiller forward speed. The variations of vibration acceleration in the different gear ratios at the engine speeds of 1400 r m^{-1}, 1600 r m^{-1}, 1800 r m^{-1}, 2000 r m^{-1} and 2200 r m^{-1} were about 0.11 m/s^2, 0.13 m/s^2, 13 0.3 m/s^2, 0.2 m/s^2, and 0.25 m/s^2, respectively. The reason for these variations might be attributed to the trailer oscillations due to changing the forward speed.

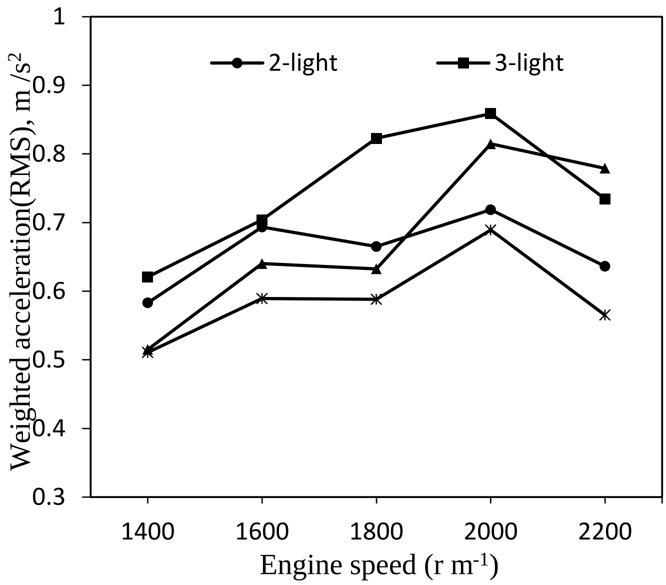

Figure 11 The effect of engine speed on the total equivalent acceleration, A(8), for the different gear ratios at the trailer seat position.

The equivalent trailer seat acceleration, A(8), is compared with the standard exposure limits for whole body vibration in Figure 12. As depicted in this Figure, the weighted acceleration at the trailer seat exceeded the allowable limits for the reduced comfort boundary and fatigue-decreased boundary as well as it is about surpass of the exposure limit for eight hours working per day. Sam and Kathirvel (2006) have also reported that the allowable exposure time was eight hours for a power tiller pulling an empty trailer in transportation on asphalt rural road, and four hours in farm road.

Figure 13 shows the maximum and minimum values of 1/3rd octave acceleration of the trailer seat position at the vertical direction for the different engine speeds and gear ratios which are compared to standard allowable driving time (ISO standard No. 2631, 1997) in the frequency range of 1 to 80 Hz. As shown in this Figure, the standard allowable driving time at frequency ranges of 4-6.3 Hz and 31.5-40 Hz was shorter than eight hours per day. The maximum acceleration was in frequency range of 31.5-40 Hz that could be related to the power tiller engine speed.

For the longitudinal direction, the vibration acceleration was less than standard eight hours limit at any frequency. Unlike the vertical direction, the vibration levels for the longitudinal direction was not considerable at frequencies related to the engine speed, which could be attributed to the placement of the engine related to chassis as well as existence of the trailer connection with drawbar and their effects on the damping of vibrations in this direction. The vibration acceleration in lateral direction was also less than standard eight hours limit and its value at all frequencies was less than 0.1 m/s^2. The allowable exposure time for the longitudinal and lateral directions is reported eight hours per day for 8-hp and 11-hp power tillers in different working conditions (Sam and Katirvel, 2009; Tewari and Dewangan, 2004).

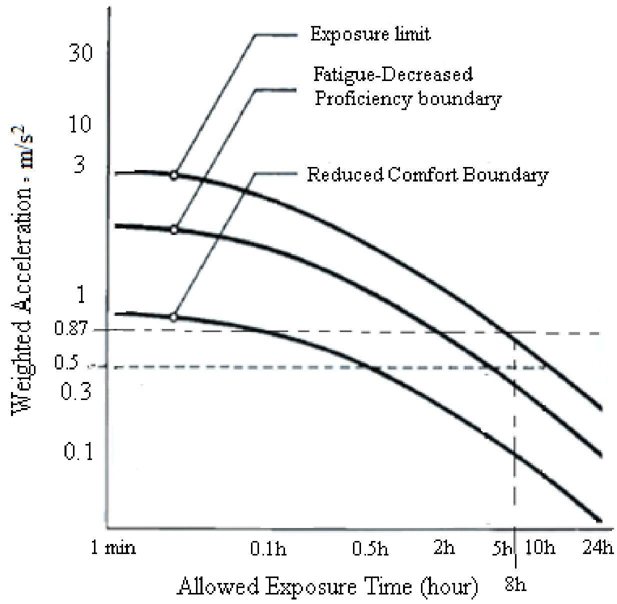

Figure 12 The equivalent acceleration for eight hours exposure to the trailer seat vibration, A(8), and its comparison with standard limits.

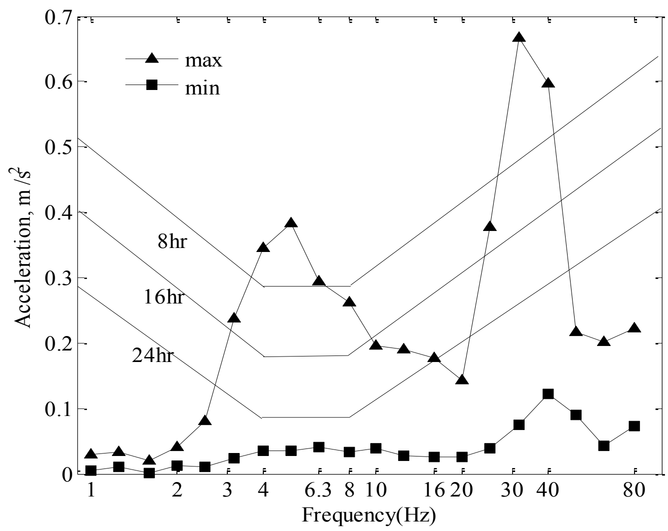

Figure 13 Comparing the maximum and minimum values of 1/3rd octave acceleration of the seat position at the vertical direction for the different engine speeds and gear ratios with standard allowable driving time.

4 Conclusions

The conclusions drawn from this research work are as follows:

1) At the power tiller handle position, the vibration acceleration peaks were occurred in the frequency of the engine rotational speed.

2) The vibration acceleration increased with increasing engine speed throughout the experiments.

3) The vibration acceleration depends on measurement direction. The experimental results indicated that the maximum and minimum values belong to vertical and longitudinal directions, respectively.

4) The amplitude of total vibration acceleration at the power tiller handle position was greater than the allowable vibration exposure limit in the frequency range of 10-80 Hz.

5) The vibration acceleration at the trailer seat in the frequency ranges of 4-6.3 Hz and 31.5-40 Hz was more than the standard limit

6) The vibration allowable exposure time for hand-arm of the power tiller operator's at eight hours working day were between 2.32 to 5.7 years for the different gear ratios and engine speeds.

7) The allowable exposure time in the heavy gears was greater than the lighter gears.

8) It is necessary to reduce the vibration transmitted to the user's hand and body by designing and developing adequate insulating systems or isolators.

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