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Short Research Article

Noise and Vibration Analysis of Power Tillers during Field Operations

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Abstract

Every day, millions of agriculture workers were exposed to noise and vibration at work and all the risks of it can entail. This paper examines the noise and vibration characteristics of popularly and most commonly used power tillers having power rating of 11 kW, 9.5 kW and 4.4 kW. Data were collected at four levels of engine speeds for stationary condition of power tiller and two operation modes for tillage and puddling operations. With the increase in engine rpm from ¼ to full of power tillers, noise and vibration magnitude was increased and the allowed exposure was reduced from 7.62 h to 2.48 h for PT-I and 9.83 h to 3.14 h for PT-II and 5.76 h to 2.21 h for PT-III during puddling operation. The SPL of the power tillers under the study was more than the permissible limit of sound level for 8-hour duration/day as recommended by ISO and hence require suitable measures to protect the operator and workers around these power tillers against excessive sound. All three power tillers showed the maximum magnitude of vibration at handle which directly interacts with the body of operator.

1. Introduction

The rate of mechanization ndian agriculture is change rapidly. Recently Indian agriculture has undergone many changes and the mechanization level increses compare to last decade. In 1951 about 97.4% farm power was coming from animate sources, while in 2001 the contribution of animate sources of power reduced to about 18%. Mechanical and electrical sources of power increased from 2.6% in 1951 to about 82% in 2001 (Shrivastava, 2005). Tractors and power tillers are being used recently iin various farm operations like tillage, puddling, intercultural operation, plant protection, irrigation, harvesting and threshing. The density (no. 1000 ha^{-1}) and population of power tiller in India is increased from 12249, 0.087 in 1986-87 to 137870, 0.971 in 2001-02 respectively (Singh, 2005). Power tillers have been found to give a benefit cost ratio of 2.30 in rice farming system with high quality work though puddling of field (Pandey, 2005). The timely operation is an important constraint in farming. The timely operation of improved machines increases workload on the operators as well as occupational hazards and diseases, which impair the performance of the operators. In farm works, the fatigue and discomfort, which human beings are subjected is not only due to physical labour, but also the noise as well. Exposure to excessive noise and vibration can lead to acute or chronic health effect. Besides physical exertion , one of the major source of discomfort for power tiller operators is the noise which are subjected for doing work.

Noise is usually defined as unwanted sound. In the frequency of about 15 to 16,000 Hz sound is audible and sensed by ear. Noise has several undesirable effects. In agricultural operations tractors, power tillers, threshers, combine harvesters and spray pumps generate noise. Exposure duration of 40 h per week to noise (in the level of 90 dB) is considered to be safe and noise level above this limit are bound to cause noise induced hearing loss (NIHL), for exposure duration of 8 h per week. Invariably the farm machinery operators are exposed to noise levels above 90 dB during Rabi season of agricultural operations. Most of farm machinery operators are suffering from noise induced hearing loss. The safe exposure duration to noise according to the Occupational Safety and Health Administration (OSHA) is presented in table 1.

Vibration is the mechanical motion of a machine or part back-and-forth from its point of equilibrium. Excessive vibration felt at the handle grip is observed as the important shortcomings in field operation of the power tiller (Pawar, 1978). The vibration from the handle of the hand tractor gets transmitted to the hands, arms and shoulders. Vibration transmitted to the operator causes discomfort and pain (Tewari et al., 2004). Discomfort and pain result in early fatigue. Christensen et al. (2000) reported that time integrated fatigue may lead to different types of injuries during the operation of the machinery. Practical experiences reveal that under different field conditions the human body is strained much more during driving the power tiller. The operator of power tiller is exposed to noise, dust, vibration, exhaust fumes, rain, and sunshine, etc. Power tiller operators have lots of problem like pain in shoulder, fatigue due to hand transmitted vibration at handles and postural discomfort. So a comparative study of noise and vibration for three most common and popularly used power tillers was conducted at Department of Farm Machinery and Power, Indira Gandhi Krishi Viswavidyalaya, Raipur (Chhattisgarh).

2. Materials and Methods

2.1. Experimental conditions

The experiments were conducted with power tillers in the open field to study the noise propagation in stationary condition, tillage and puddling operations. There was no obstruction like trees, buildings, solid fences, rocks and other objects in the radius of 100 m. The surface area of the experimental site was free from acoustically absorptive materials like tall grasses, standing crops etc. The experiments were conducted during the morning (5.00 am to 9.00 am) and evening (4.00 pm to 7.00 pm) hours so as to minimize the errors due to background noise. The ranges of average mean dry bulb temperature, relative humidity and wind velocity during the experiment were 21.2±2.1^{0}C, 71.4±3.2% and 1.1±0.26 m s^{-1} respectively. The texture of the soil at experimental plot was 61.9% sand, 11.6% silt and 25.4% clay and the type of soil was lateritic with sandy loam. The average moisture content and bulk density before operation were 16.42% (dry basis) and 1.66 g cm^{-3} respectively. The experimental conditions find suitable to conduct noise measurement experiment according to the test code IS -12180:2000, ISO-7216:1992.

Three most popular and commonly used models of power tillers in India were selected for the study. Their brief specifications are given in table 2. The tyres fitted to these machines were of standard size and the depth of tread was not less than 65% of the depth of new tread. The recommended tyre inflation pressure was maintained.

2.2. Experimental procedure

2.2.1. Noise propagation

For studying the sound propagation characteristics in terms of sound pressure level (SPL), grid points were marked in the field using cross staff, ranging rod and measuring tape at a grid spacing of 1.0 m in1.0 m. The hand tractor was kept at the center of the grid lines with engine operating at full throttle. The center of the right wheel of power tiller was considered as (0,0) coordinate. The noise was measured accordance with the guidelines given in ISO-1999 standard and IS-5994 standards. Digital sound level meter of SL 4001 (Lutron) was used having inch digit LCD display,18 mm size, function dB (A and C weight) fast, slow and maximum hold response. For tillage and puddling field operations the hand tractors were operated with most commonly used matching implements cultivator and rotavator. For on road test all the three power tillers were operated on grass land, tar road and bitumen road for transport operation with empty trailer. Low gears 2nd and 3rd were selected for both operations due to higher requirement of draft. Four levels of engine rpm were selected as ¼th, ½, ¾th and full. As there are no gears in PT-III, it was operated only at different engine speeds. The sound level readings were recorded in digital sound level meter by holding it at a height of 1.0 m from the ground level for 30 seconds at each grid points. The readings were taken on each grid point up to a distance where the sound level attenuated to below 75 dBA. The equivalent sound level (L) recorded by the sound level meter at each grid point was used to draw the contour of sound level at the interval of 2 dBA. Three replications were conducted for obtaining each reading.

2.2.2. Vibration mapping

The vibration from the handle of the power tiller is transmitted to the hand arm of the operator through the palm of his hand. The hand-transmitted vibration was measured at handle-grip level as per the guidelines of ISO 5349 (1986). The transducer was mounted on handle in left hand side of each power tiller since the left hand is always in contact with handle. The right hand was used for operating the controls. The orientation of the

Table 1: Permissible noise exposure for occupational noise recommended by OSHA

Duration day^{-1}, hours	Sound level, dB(A)	Duration day^{-1}, hours	Sound level, dB(A)
8	90	1.50	102
6	92	1.00	105
4	95	0.50	110
3	97	0.25	115
2	100	--	> 115

Table 2: Brief specification of power tillers

Power tiller	Rated power, kW	Rated engine speed, rpm	Gears
PT-I	11.0	2000	6 forward, 2 reverse
PT-II	9.5	2300	6 forward, 2 reverse
PT-III	4.4	1500	No gears

measurement axes of the accelerometers was kept according to ISO 5349. The Z- axis was directed along the second metacarpus bone of the hand, X- axis perpendicular to the Z-axis (both these axes are normal to the longitudinal axis of the grip) and Y-axis, (parallel to the longitudinal axis of the grip). A magnetic sensor was fixed on the part, to read the vibration at the particular part. The read button was pushed and display showed the vibration level on digital display screen.

As the major source of induced vibration is the engine and the vibrations are transmitted to operator through handle in walking type power tiller and through handle and seat in riding type power tiller, the vibration meter was mounted on engine top, chassis, transmission gear box, root of handle bar and handle for walking type power tiller and engine top, chassis, transmission gear box, root of handle bar, handle and seat for seating type power tiller. The trail was conducted for different engine rpm (1/4, 1/2, 3/4 and full) for all power tillers. Each trail was repeated for three times with an acquisition period of 30 seconds.

3. Results and Discussion

3.1. Noise propagation

Sound Pressure Level (SPL) of all the power tillers was found to be increasing with the increase in engine speed. For PT-I with the increase in engine rpm from ¼th to full, equivalent sound pressure level increases linearly from 93.1 to 98.8 dB (A) and 90.3 to 96.1 dB (A) at exhaust and at operator's ear level respectively. SPL of PT-II was increased linearly from 89.3 to 95.4 dB (A) at exhaust whereas at operator' ear level it was linearly increased from 87.4 to 93.4 dB (A) with the increase in engine rpm from ¼th to full. PT-III shows the same trend as that of PT-I and II. SPL at exhaust was found highest for PT-III which increased from 92.7 to 100.3 dB (A). Alike at the exhaust, SPL was increased linearly from 91.8 to 99.7 dB (A). The results were found similar with study conducted by Dewangan et al. (2005). For PT-I,PT-II and PT-III the area of 3.5 m, 2 m and 5.6 m was found above SPL of 90 dB(A) that means the operator and also other persons working at distance of away from power tiller will have noise exposure more than 90 dB (A).

3.2. Sound pressure level during tillage operations

For tillage operation SPL at operators ear level of power tillers I, II and III ranged from 90.85 to 101.97 dB (A). Noise level was found above the safe working time of 8 h per day as per OSHA guidelines. The average value of SPL of PT-I at 2nd low gears was increased by 6.87% with increase in rpm from ¼th to full, whereas at 3rd low gear the value was increased by 7.25%. In PT-II increase in engine rpm from ¼th to full the noise was increased by 5.42 dBA at 2nd low gear but at 3rd low gear the noise was increased by 5.70 dBA. For PT-III the average value of noise was increased from 94.07 to 101.97 dBA with the increase in engine rpm from ¼th to full (Figure 1)

In comparison of all three power tillers noise at operator's ear level, PT-III gave the maximum value at all levels of engine rpm. Noise level was found to be more in PT-I as compared to PT-II, the increase being 3.31%. The maximum noise recorded was 101.4 dBA, 98.2 dBA and 102.3 dBA for PT-I, PT-II and PT-III respectively. Maximum noise was found for the lower power rating power tiller, this may be due to the design of muffler which do not reduce the magnitude of sound.

3.3. Sound pressure level during puddling operations

SPL at operator's ear level for all three power tillers in wet tillage increased linearly with the engine rpm. Noise was increased from 90.2 dBA to 98.6 dBA, 88.9 dBA to 96.6 dBA and 92.5 dBA to 99.8 dBA with the increase in engine rpm from ¼th to full for PT- I, PT-II and PT-III respectively. The SPL was more in case of PT-III though the horse power is lower than that of other two power tillers. This may be due to the poor design of muffler of PT-III (Figure 2).

With the increase in engine speed from ¼th to full, the exposure limit was reduced from 7.62 h to 2.48 h for PT-I and 9.83 h to 3.14 h for PT-II and 5.76 h to 2.21 h for PT-III during puddling operation (Figure 3&4). Magnitude of noise exceeded the safe working limit of 90 dBA at all selected levels of gears and engine rpm for all the power tillers except at 2nd low gear and ¼th engine rpm for PT-I. As a risk of hearing loss increases with level and duration of exposure, it should be noted that 90 dBA limit for 8 h was the safe exposure limit designed to reduce but not to prevent hearing damage (Binisam et al., 2004).

The SPL at operator's ear level during tillage operation was increased linearly with increase in engine rpm with shifting gear from 2nd low to 3rd low. This may be due to increase in

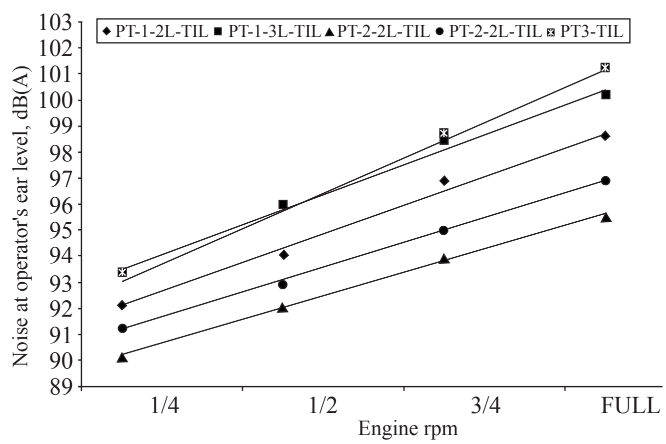

Figure 1: Noise at operators' ear level during tillage operation at different engine rpm of power tillers

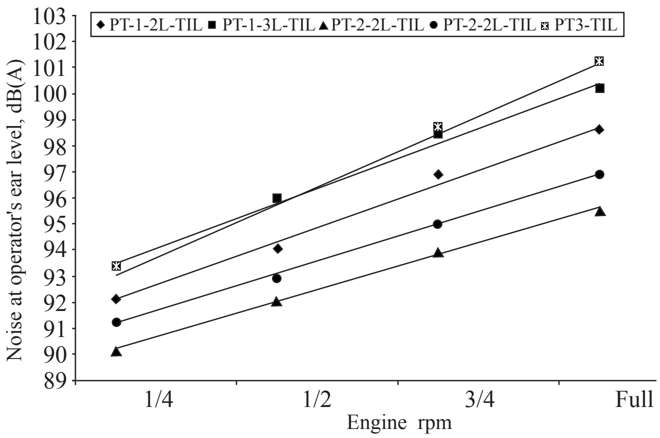

Figure 2: Noise at operators' ear level during puddling operation at different gears of power tillers

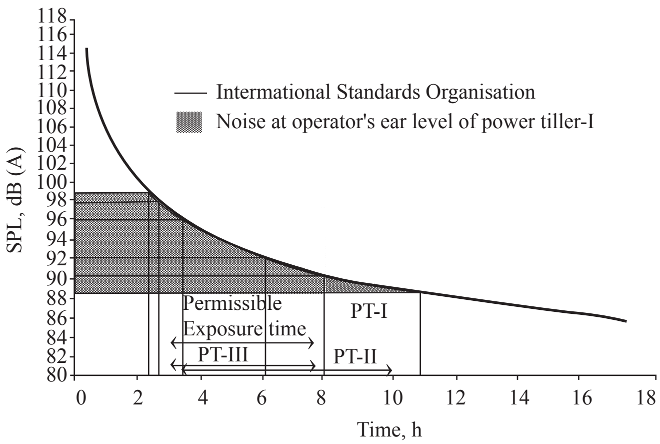

Figure 3: Noise and exposure time relationship for power tiller in tillage operation

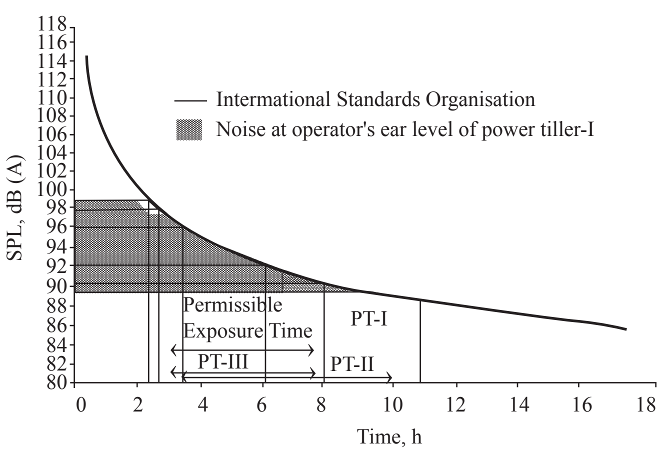

Figure 4: Noise and exposure time relationship for power tiller in puddling operation

traveling speed of the power tiller. As the speed of operation is increased, the blade of the rotor requires more force to till the soil which consequently increases the load on the engine. As a result, the combined sound at exhaust, gear box and the sound at rotor due to interaction of blades with soil at higher speed increase the noise at operator's ear level.

3.4. Vibration mapping

Among all three power tillers, PT-I showed the highest magnitude of vibration at all the locations. This might be due to the higher rated horse power produced by the engine of PT-I (11 kW) compared to PT-II (9.5 kW) and PT-III (4.4 kW). The increase in peak value of vibration for PT-I was 1.66 to 3.74% at engine top, 8.08 to 99.27% at chassis, 19.04 to 43.39% at gear box, 0.00 to 42.26% at root of handle and 14.89 to 15.09% at handle with the increase in engine speed from ¼ to full when compared to PT-II (Figure 5).

Whereas compared to PT-III, PT-I showed 293.54 to 420% increase at engine top, 35.44 to 63.47% increase at chassis, 9.18% increase at root of handle and 14.54 to 29.49% increase at handle, whereas 220 to 378.94% decrease at gear box when engine rpm increased from ¼th to full. This might be due to difference in power rating of power tillers. All three power tillers showed the maximum magnitude of vibration at handle which directly interacts with the body of operator.

The handle of the power tiller showed higher vibrations than other parts of power tiller because the handle of the power tiller acts like a cantilever beam. It was subjected to forced as well as free vibrations. Vibrations at the engine top were also in the higher range since the major excitation of vibration of power tiller is the unbalanced inertia force of the engine (Qunying et al., 1989). The magnitude of vibration at the gear box was lower as compared to other parts, since the free movement of the gear box was restricted by the pneumatic wheels supported on the ground, which act as vibration damping medium. The reason behind the lower magnitude of vibration at the root of handle bar was that the longitudinal movement was restricted because the end of the handle was attached rigidly to the frame of power tiller and hence showed lower magnitude of vibration compared to handle. The seat showed the maximum value of vibration next to handle followed by engine top and it was due to the free vibrations in addition of forced vibrations since it was attached to power tiller as a separate unit and whose vibrations will change as per the mass.

3.5. Handle arm vibration (HAV) during tillage operations

The influence of different gears and different engine rpm on handle arm vibrations during tillage operation with all power tillers is presented in the Figure 3. It is found that HAV was increased linearly with the increase in engine rpm for all the power tillers. The average HAV was increased from 0.1069 m/s to 0.1568 m/s with the increase in engine rpm from ¼th to full for PT-I whereas for PT-II and PT-III, the value were increased from 0.0826 m/s to 0.1362 m/s and 0.0731 m/s to 0.1251 m/s respectively (Figure 6).

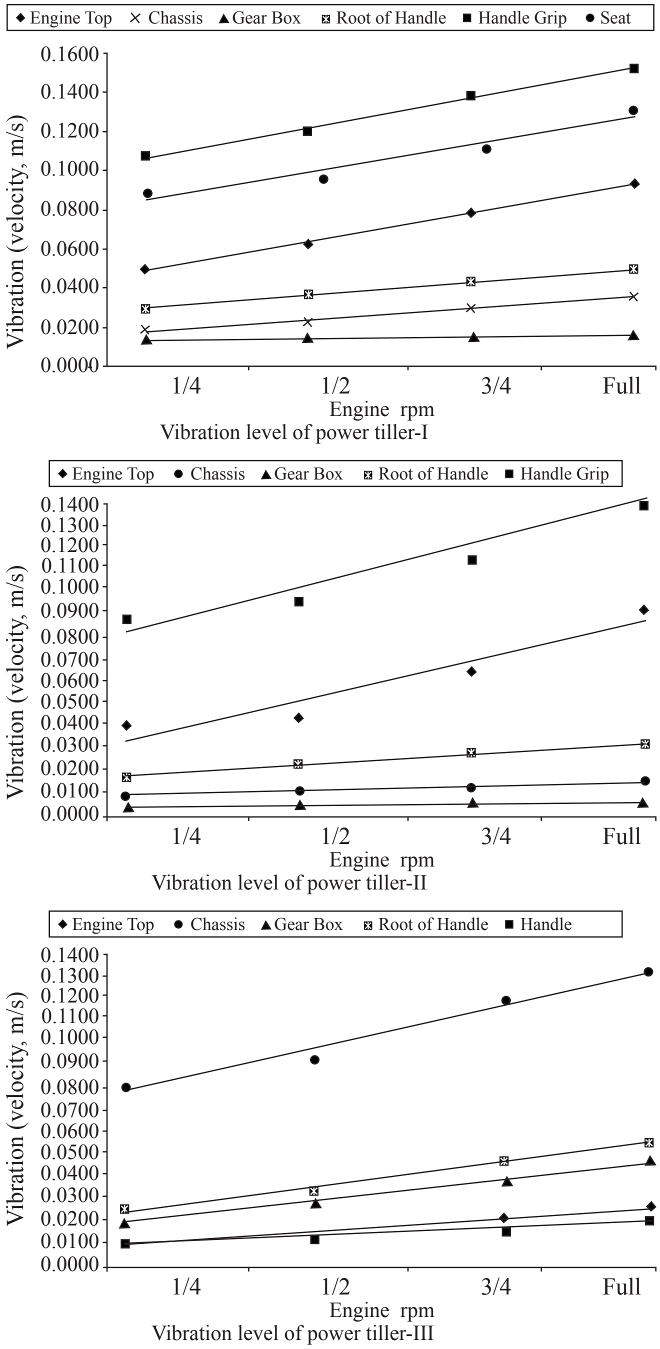

Figure 5: Vibrations levels of different power tillers at different engine rpm at different location

For PT-I and PT-II, it was found that at particular engine rpm if the gear is shifted from 2nd low to 3rd low, the vibrations at handle was increased. It was increased by 6.3, 5.9, 2.4 and 4.0% for PT-I but the values for PT-II were increased by 2.7, 8.5, 5.7 and 2.7% at ¼th, ½, ¾th and full engine rpm, respectively. Due to increase in forward speed of operation by shifting the gear to higher level, the force required to till the soil in rotary mode is increased which ultimately increase the load on the engine

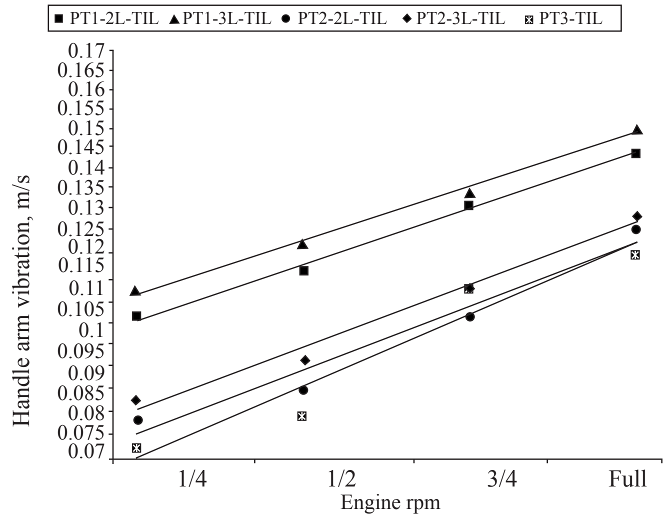

Figure 6: Handle arm vibration during tillage operation at different gears of power tillers

results in increase in the magnitude of vibrations at handle. In case of PT-III, the value of HAV was linearly increased with the increase in engine rpm from ¼th to full. The magnitude of HAV was increased by 66.38% with the increase in engine rpm from ¼th to full. On comparing the HAV of all the power tillers, it is found that magnitude of vibration is increased with the increase in the power rating of power tiller. The similar findings were discussed by the various researchers (Celen et al., 2003).

3.6. Handle arm vibration (HAV) during puddling operations

The hand arm vibrations of all power tillers at all selected levels of gears and engine rpm during puddling operation is depicted in Figure 5. It is quite evident from the figure that PT-I showed higher hand arm vibration values at both selected gears when compared to other two power tillers. Magnitude of HAV was increased linearly with the increase in engine rpm from ¼th to full. In case of PT-I, the magnitude of HAV was ranged from 0.1034 m/s to 0.1444 at 2nd low gear which was increased at 3rd low gear from 0.1093 to 0.1519 m/s with the increase in engine rpm from ¼th to full. The increase in HAV was 39.65 and 38.97% at 2nd low and 3rd low gears respectively. At full engine rpm the average magnitude of HAV was 74.1% higher as in case of ¼th engine rpm (Figure 7).

On comparing the values of HAV of all the power tillers, it is marked that higher values were obtained in PT-I proceeding by PT-II and lower value were observed in PT-III. All the power tillers were of single cylinder but of different power ratings. Higher horse power engine develops the higher torque. Since the major vibration contribution was the power stroke of the engine, as the engine speed increased more power strokes are completed second^{-1} and the different components of power tiller vibrate frequently and resulted in higher values of vibrations

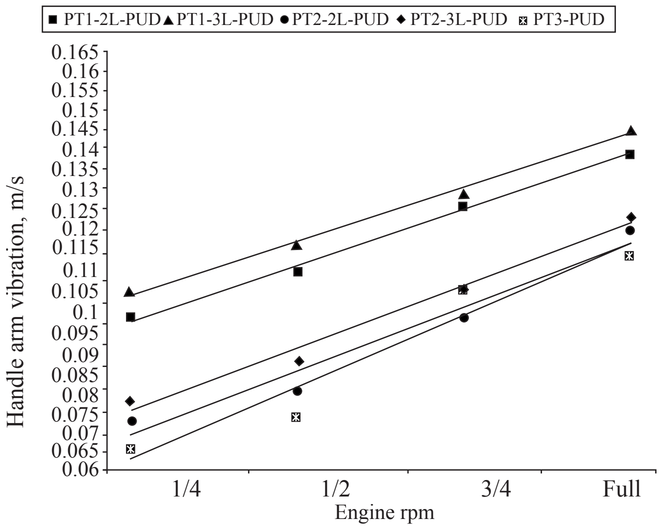

Figure 7: Handle arm vibration during puddling operation at different gears of power tillers

4. Conclusion

The SPL increases with the increase in engine rpm. Density of noise contour is proportional to the engine rpm or load. Maximum noise was generated by power tiller-III followed by power tiller-I and power tiller-II. Permissible exposure limit to noise was reduced from 7.62 h to 2.48 h for PT-I and 9.83 h to 3.14 h for PT-II and 5.76 h to 2.21 h for PT-III during puddling operation. In comparison of PT-I, II and III, PT-I showed the highest magnitude of vibration at all the location.

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