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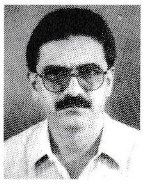
Vibration Mapping of Walking and Riding Type Power Tillers

by



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Abstract

The major excitation of the vibration of the power tiller is the unbalanced inertia force of the engine. Further vibration exciting forces are the transmission system. The mechanical vibration is transmitted to the human body through the handle and seat. The magnitude of mechanical vibration at different components of the power tiller system is essential for identifying the source of vibration and providing vibration isolators to increase the safe exposure limit of operators. The mechanical vibration of walking and riding type power tillers was measured at different locations in stationery condition, during rototilling in untilled and tilled soil and in transport mode on bitumen and farm roads. Comparing the acceleration at the different locations, the vibration at the top of the engine was highest followed by chassis, handle, root of handle bar and gear box for both walking and riding type power tillers. In stationary mode the increase in engine speed resulted in two fold increase in machine vibration at handle for both power tillers. Among the power tillers the vibration at handle was higher by 72.94 to 170 percent for the riding type power tiller. In field operation and transport mode the increase in forward speed of operation resulted in increased values of acceleration. The magnitude of vibration was higher at handle (40.50 percent) and seat (28.08 percent) in untilled field than tilled field. In transport mode farm road induced higher vibration than bitumen road. Among the power tillers the vibration induced in walking type power tiller was higher during field operation whereas in transport mode power tiller (8.95 kW) exhibited higher values.

Introduction

The operator of a power tiller has to endure various environments and stresses. The environment includes all the factors in the surroundings which have an effect on man-machine system. Among these factors, mechanical vibration is more important because it significantly accelerates fatigue and affects sensitivity and reaction rates of the operator. Excessive noise level, vibrations and uncomfortable posture are the important shortcomings in power tiller design (Pawar, 1978). Mechanical vibrations have instantaneous and long term effects upon the human body. Walking control and riding control type power tillers are in use at present. In walking control type, a random vibration is transmitted to the operator's chest through his hands (hand transmitted vibration). In case of a riding control type, two possible types of vibration are transmitted to the operator's body, one is through seat as whole body vibration (WBV) and other is through his hands as hand transmitted vibration (HTV). In this paper the mapping of mechanical vibration transmitted from the engine to the handle is reported.

Review of Literature

Vibration affects human performance. It is usually characterized by its frequency, acceleration and direction. It affects the whole body (Whole body vibration) and it affects parts of it, such as the hands (Hand transmitted vibration). Both whole body and local vibration can cause vibration throughout the body (Rodahl, 1989). Vibration is defined as oscillatory motion about a fixed point. A vibration is called periodic when the oscillation repeats itself. Vibrations primarily are of two types (Sanders and McCormick, 1993). In the first type of vibration, the body continues to vibrate at the same frequency over a considerable period of time. The simplest way of describing this motion is by a sinusoidal equation. The other type of vibration is that of one-time shocks and impacts, called non periodic vibrations. Majumder (1994) reported that analysis of power tiller vibration in stationary condition was complex. Acceleration and frequency of vibration changed depending on engine speed and experimental conditions. These were increased with an increase in engine speed. The human body reacts to the different kinds of vibration in various ways. The human body is not rigid, and different body parts vibrate differently even if they are under the influence of the same linear vibration (Kroemer et al., 2000). Vibration seems to generate muscle reflexes, which have a protective function, causing the extended muscle to shorten. The reflex activity of the muscles also explains the often observed increase in energy consumption, heart rate and respiratory rate when a person is exposed to strong vibrations. These vibrational effects on metabolism, circulation and respiration are small and have little significance (Kroemer and Grandjean, 2000).

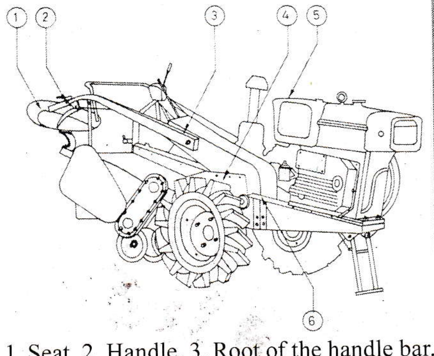
Methods and Materials

Machine vibration of different components in stationary mode as well as handle and seat vibrations under operating conditions in field and on road were measured to know the magnitude of vibration transmitted to the subject.

Vibration Characteristics at Stationary Mode

The idea of measuring the vibrations of a power tiller in a stationary mode was to determine the vibration of the machine in free moving mode without any influence of the human operator. The major source of induced vibration is the engine and the vibrations are transmitted to the operator through the handle in the walking type power tiller (A) and through handle and seat in riding type power tiller (B), therefore the accelerometer was mounted on the engine top, chassis, transmission gear box, root of handle bar and handle for power tiller A and engine top, chassis, transmission gear box, root of handle bar, handle and seat for power tiller B as shown in **Fig. 1**. The machine vibration was measured using the ENDEVCO Istron model 751-10 accelerometer of the B & K instrument. Vibration signals in the vertical mode were recorded by employing Fast Fourier Transform (FFT) technique using the FFT analyzer built in the PULSE multi-analyzer system. FFT is a powerful analytical tool which transforms the random time domain data into highly descriptive frequency data. The trial was conducted for different engine speeds for both power tillers. Each trial was repeated for three

Fig. 1 Components showing measurement of machine vibration



1. Seat, 2. Handle, 3. Root of the handle bar, 4. Transmission gear box, 5. Engine top, 6. Chassis.

Fig. 2 Accelerometer on handle of power tiller A

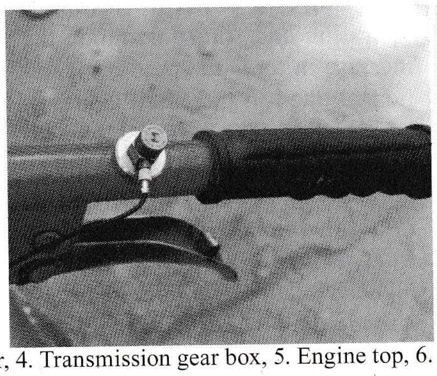
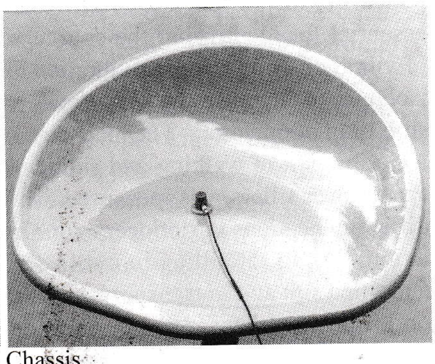


Fig. 3 Accelerometer placed on metallic seat of power tiller B



times with an acquisition period of 30 sec and the peak value obtained from the spectrum was averaged for each engine speed. The views of the accelerometer placed on the handle of power tiller A and on the seat of power tiller B are shown in **Fig. 2** and **3**, respectively.

Vibration Characteristics in Rototilling Operation

The measurement of machine vibration during tillage was aimed to determine the vibration level of the power tiller with the influence of implement during field operations, as well as the effect of terrain in order to understand the amount of vibration transmitted to the body by comparing with the hand transmitted and whole body vibration. The measurements were taken in untilled and tilled fields using rotovator. The accelerometer was mounted on the root of handle bar and handle for the power tiller A and on the root of handle bar, handle and underneath the seat for power tiller B.

Vibration Characteristics in Transporting Operation

The vibration characteristics of the power tiller handle and seat are different while riding a power tiller with an empty trailer. Therefore, vibration levels were measured on the root of handle bar, handle and underneath the seat for power tiller A and power tiller B during transport on farm roads and bitumen roads.

Results and Discussion

Vibration Characteristics at Stationary Mode

a. Power Tiller A

The peak acceleration values obtained from the vibration spectrum for power tiller A at different engine speeds are presented in **Table 1**.

As the engine speed increased, the peak acceleration also increased at different locations. Since the major vibration contribution was the power stroke of the engine, as the engine speed increased more power strokes are completed per second and the different components of power tiller vibrate frequently and resulted in higher values of acceleration. The increase in engine speed of power tiller A from 900 to 2,300 rpm resulted in two fold increase in vibration at engine top, nearly six fold increase at the chassis, four fold increase at the gear box, three fold increase at the root of handle bar and two fold at the handle.

Comparing the acceleration at the different locations of power tiller A, it was found that the vibration at the top of the engine was highest followed by chassis, handle, root of handle bar and gear box. The vibration at the top of the engine was the highest since the major excitation of the vibration of the power tiller was the unbalanced inertia force of the engine (Jiao Qunying et al., 1989; Dong, 1996 and Ying et al., 1998). The vibration magnitude at the gear box was the lowest among other locations, 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 handle of the power tiller showed higher acceleration than at root of handle bar because the handle of the power tiller was like a cantilever beam. It was subjected to forced as well as free vibrations. The longitudinal movement of the root of handle bar was restricted because the end of the handle was attached rigidly to the frame of the power tiller and hence showed lower magnitude of vibration compared to the handle.

Table 1 Machine vibration of power tiller A in stationary mode

Engine speed, rpm	Peak acceleration, ms^{-2}				
	Engine top	Chassis	Gear box	Root of handle bar	Handle
900	12.1	3.35	0.52	2.44	4.25
1200	14.0	4.74	0.62	2.65	5.25
1500	16.0	6.10	0.72	2.98	5.70
1800	18.2	11.60	1.12	3.07	6.13
2000	24.3	11.90	1.59	4.31	6.25
2300	25.8	20.90	2.03	7.42	9.14

Table 2 Machine vibration of power tiller B in stationary mode

Engine speed, rpm	Peak acceleration, ms^{-2}					
	Engine top	Chassis	Gear box	Root of handle bar	Handle	Seat
900	18.05	6.61	0.77	2.66	7.35	12.75
1200	19.20	14.45	0.85	5.24	10.95	15.55
1500	40.75	15.40	1.69	4.83	11.27	17.25
1800	53.25	25.65	2.24	8.45	13.20	18.35
2000	54.20	27.05	2.90	9.49	16.90	19.30

b. Power Tiller B

The peak acceleration values obtained from the vibration spectrum for power tiller B at different engine speeds are shown in **Table 2**.

As in power tiller A, the acceleration values increased with engine speed at all locations (Majumder, 1994 and Mamansari, 1998). The increase in engine speed from 900 to 2,000 rpm resulted in three fold increase in vibration at the engine top, nearly four fold increase in the chassis, four fold increase at the gear box, four fold increase at the root of handle bar, two fold at the handle and one and half fold increase at the seat of the power tiller B. The highest value of acceleration was obtained at the top of the engine followed by chassis, seat, handle, root of handle bar and gear box as observed in power tiller A. The seat showed the highest value of acceleration, after the engine top, followed by chassis. This was due to the free vibrations in addition of forced vibrations since the seat was attached to the power tiller as a separate unit and whose vibrations change as per the mass. The increase in the engine speed from 900 to 2,000 rpm resulted in an increased peak value of acceleration by 130 percent for the handle and 51.37 percent for seat.

Comparing power tillers A and B, power tiller B showed highest values of acceleration at all locations measured at the same engine rpm as depicted in **Fig. 4**. The increase in peak value of acceleration for the power tiller B was 49.17 percent to 123 percent at the engine top, 97.3 to 127 percent at the chassis, 47.78 to 82.70 percent at the gear box, 9.01 to 120 percent at the root of the handle bar, 72.94 to 170 percent at the handle with the increase in engine speed from 900 to 2,000 rpm when compared to the power tiller A. This might have been due to the higher rated horsepower produced by the engine of the power tiller B (8.95 kW) compared to power tiller A (7.46 kW). In addition, the positioning of the handle and seat with respect to the engine was at a greater distance (1,850 and 2,270 mm) for power tiller B as compared to the power tiller A (1,170 and 2,150 mm). Since the handle and seat of power tiller B was positioned further from the engine compared to power tiller A, these parts were subjected to more free vibrations.

Vibration Characteristics in Rototilling Operation

a. Power Tiller A

The highest value of acceleration obtained from the vibration spectrum for power tiller A at selected forward speeds in untilled and tilled fields are shown in **Table 3**. It was observed that the magnitude of acceleration on the root of the handle bar and handle increased with increase in selected levels of forward speed in both untilled and tilled field. A two fold increase in peak acceleration on the handle was recorded with increase in forward speed from 1.5 to 2.4 km h^{-1} in untilled fields. Similarly, in tilled fields the increase in acceleration was 53.96 percent as the forward speed increased from 1.5 to 2.4 km h^{-1}.

The peak acceleration on the handle was higher in untilled filed

Fig. 4 Machine vibration of power tiller A and B in stationary mode

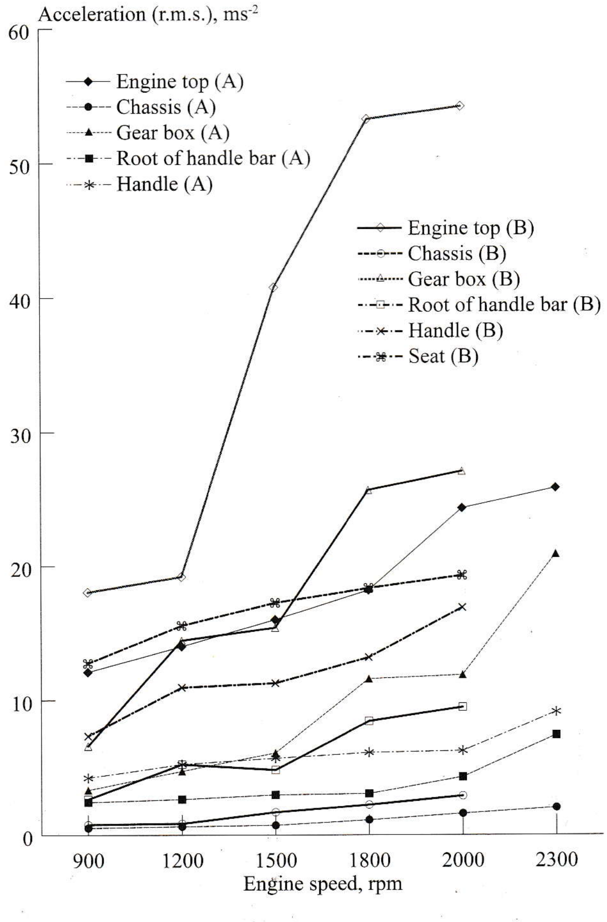
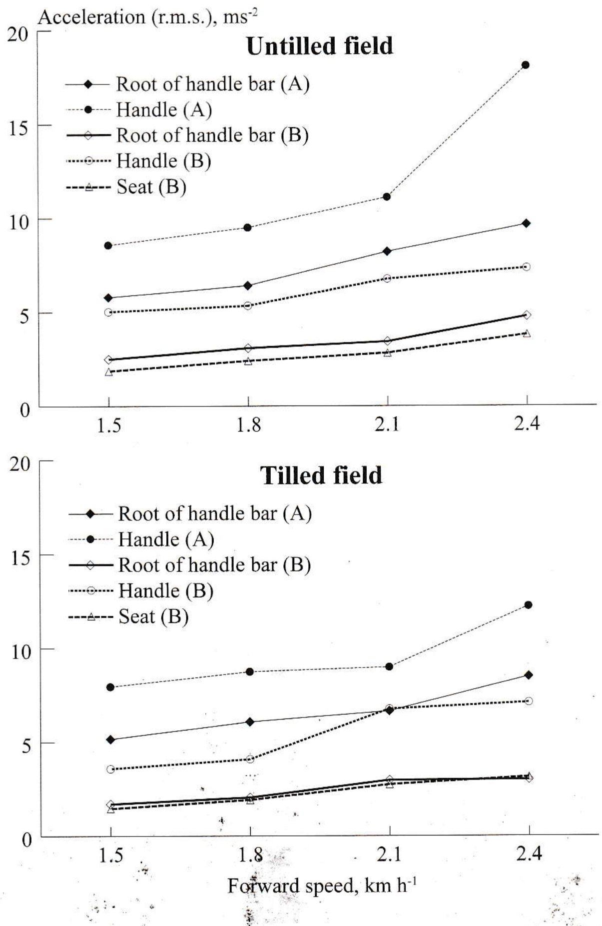


Fig. 5 Machine vibration of power tiller A and B during rototilling operation



than tilled field. The percentage increase in peak acceleration in untilled fields, when compared to tilled fields, was 12.51 to 13.50 percent at the root of handle bar and 7.86 to 47.74 percent at the handle with the increase in forward speed from 1.5 to 2.4 km h^{-1}. This indicated the effect of terrain induced vibration through wheels (Clijmans et al., 1998). Since the untilled field was dry, rough and compact compared to tilled field, damping effect was less in untilled fields. Also, the presence of root stalks of previous crops and biting of tines on hard soil might add vibration to the system. Hence, the magnitude of vibration was higher in untilled fields compared to tilled fields.

b. Power Tiller B

The peak value of acceleration obtained from the vibration spectrum for power tiller B at selected forward speeds in untilled and tilled fields is shown in **Table 4**.

Increase in forward speed from 1.5 to 2.4 km h^{-1} resulted in an increased peak value of acceleration by 91.6 percent at the root of handle bar, 46.12 percent at the handle and 104 percent at the seat in untilled fields. Similar results are observed in tilled fields in which the increase in magnitude of acceleration varied from 77.6 percent at root of handle bar, 99.16 percent at handle and 116 percent at seat as the forward speed increased from 1.5 to 2.4 km h^{-1}. The peak acceleration on the handle and underneath the seat was higher in untilled fields (**Fig. 4**) than in tilled fields as observed in power tiller A (Clijmans et al.,1998).

Comparison between handle vibrations of power tillers A and B during rototilling showed that acceleration values were higher for power tiller A than power tiller B both in untilled and tilled as depicted in **Fig. 5**. This might be due to the fact that power tiller B was a riding type power tiller and the seat was rigidly attached to the power tiller with a rear wheel below the seat. Since the vibration was measured during the actual field condition, the total weight of the power tiller B (581 kg) was higher than that of power tiller A (442 kg) since it included the weight of the subject also. This provided additional damping to the system and hence resulted in lower values of acceleration for power tiller B.

Table 3 Machine vibration of power tiller A during rototilling

Forward speed, km h^{-1}	Peak acceleration, ms^{-2}			
	Untilled field		Tilled field	
	Root of handle bar	Handle	Root of handle bar	Handle
1.5	5.80	8.58	5.16	7.95
1.8	6.42	9.51	6.08	8.75
2.1	8.22	11.12	6.66	9.00
2.4	9.67	18.10	8.52	12.24

Table 4 Machine vibration of power tiller B during rototilling

Forward speed, km h^{-1}	Peak acceleration, ms^{-2}					
	Untilled field			Tilled field		
	Root of handle bar	Handle	Seat	Root of handle bar	Handle	Seat
1.5	2.50	5.03	1.87	1.70	3.58	1.46
1.8	3.09	5.35	2.41	2.05	4.09	1.92
2.1	3.44	6.77	2.83	2.97	6.77	2.74
2.4	4.79	7.35	3.82	3.02	7.13	3.16

Table 5 Machine vibration of power tiller A with trailer on transport mode

Forward speed, km h^{-1}	Peak acceleration, ms^{-2}					
	Farm road			Bitumen road		
	Root of handle bar	Handle	Seat	Root of handle bar	Handle	Seat
3.5	3.89	4.34	1.31	3.70	3.34	0.941
4.0	4.53	5.08	1.32	4.31	4.86	0.997
4.5	4.91	6.44	1.40	4.65	5.30	1.260
5.0	5.05	6.63	2.49	4.70	5.32	1.380

Table 6 Machine vibration of power tiller B with trailer on transport mode

Forward speed, km h^{-1}	Peak acceleration, ms^{-2}					
	Farm road			Bitumen road		
	Root of handle bar	Handle	Seat	Root of handle bar	Handle	Seat
3.5	4.50	9.62	1.95	4.19	9.31	1.19
4.0	5.16	10.80	2.27	4.70	9.39	1.30
4.5	5.33	12.40	2.65	5.29	9.84	1.86
5.0	5.68	13.10	2.88	5.36	9.99	2.17

Vibration Characteristics in Transporting Operation

a. Power Tiller A

The peak value of acceleration obtained from the vibration spectrum for power tiller A at selected forward speeds on farm roads and bitumen roads are shown in **Table 5**. As observed in rototilling, increase in forward speed of the power tiller resulted in increased peak acceleration on the root of the handle bar, handle and underneath the seat. The increase in peak acceleration at handle was 29.82 percent and underneath the seat was 90.07 percent with the increase in forward speed from 3.5 to 5.0 km h^{-1} during transporting on farm roads.

As observed in rototilling, increase in forward speed of the power tiller resulted in increased peak acceleration on the root of the handle bar, handle and underneath the seat. The increase in peak acceleration at the handle was 29.82 percent and underneath the seat was 90.07 percent with the increase in forward speed from 3.5 to 5.0 km h-1 during transporting on farm road. Similar results were observed on bitumen roads in which the increase in forward speed from 3.5 to 5.0 km h^{-1} resulted in an increased peak value of r.m.s acceleration by 59.28 percent at the handle and 46.65 percent underneath the seat. The peak acceleration on the handle and underneath the seat was higher on farm roads than in bitumen roads (tar road). This clearly revealed the effect of terrain in inducing vibration. The reason for higher magnitude of vibration on farm roads was the unevenness and small undulations of farm road compared to relatively medium surface finish level on bitumen roads.

b. Power Tiller B

The peak value of acceleration obtained from the vibration spectrum for power tiller B at selected forward speeds on farm roads and bitumen roads are shown in **Table 6**.

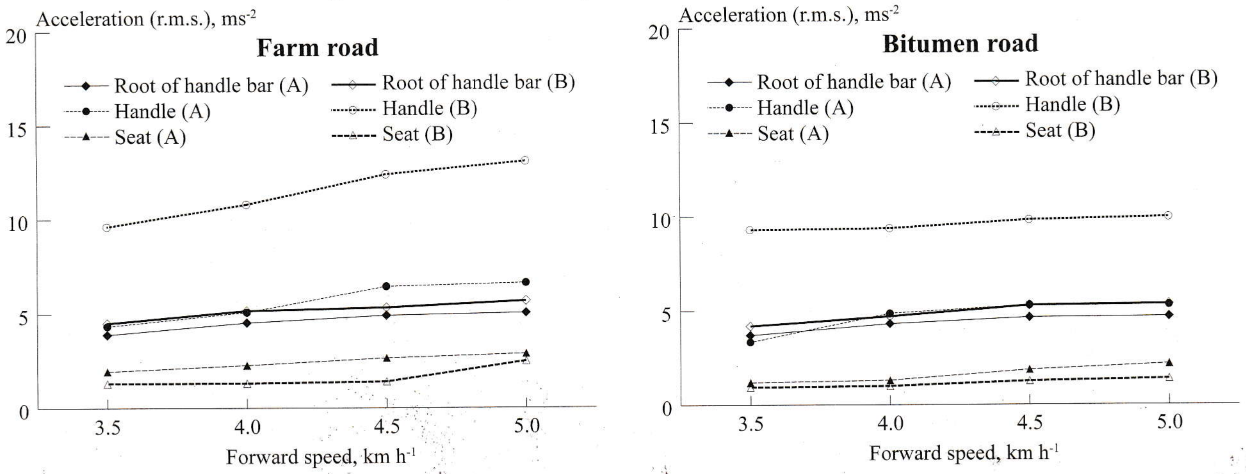
The results were similar to the earlier findings that the magnitude of vibration increased with forward speed. The values of acceleration on the handle and underneath the seat were increased by 36.17 and 47.69 percent, respectively with the increase in forward speed from 3.5 to 5.0 km h^{-1} on farm roads. On bitumen roads, the peak acceleration on the handle and underneath the seat was increased by 7.3 and 82.35 percent with the increase in forward speed from 3.5 to 5.0 km h^{-1}, respectively. Comparison between power tillers A and B showed that magnitude of vibration was higher for power tiller B than power tiller A during transport with anempty trailer as depicted in **Fig. 6**. The percentage increase in power tiller B was 15.68 to 12.47 percent at root of the handle bar, 121.65 to 97.58 percent at the handle, 48.85 to 15.66 percent at seat on farm roads and 13.24 to 14.04 percent at root of the handle bar, 178.74 to 87.78 percent at the handle, 26.46 to 57.25 percent at seat on bitumen roads with the increase in forward speed from 3.5 to 5.0 km h^{-1}. This might be due to the fact that same trailer was attached to both power tillers and hence the weight of the trailer added same vertical load to the both power tillers unlike in field operations where the total weight of the power tiller B was increased due to the seated person when compared to power tiller A. In addition, the damping effect of the terrain during transport was relatively less when compared to the field operations in which the soil mass acted as a cushion. So the same condition as that of stationary was obtained where the machine vibration of each location of power tiller B was higher than power tiller A, which was mainly due to higher rated horsepower of the engine.

Conclusions

Based on the analysis of the results the following conclusions are drawn

- In thestationary mode the increase in engine speed from 900 to 2,300 rpm resulted in two fold increase in vibration at engine top, nearly six fold increase at the chassis, four fold increase at thegear box, three fold increase at the root of handle bar and two fold at the handle of the walking type power tiller (A).
- The increase in engine speed from 900 to 2000 rpm resulted in three fold increase in vibration at engine top, nearly four fold increase in the chassis, four fold increase at the gear box, four fold increase at the root of handle bar, two fold at the handle and one and half fold increase at the seat of riding type

Fig. 6 Machine vibration of power tillers A and B transport mode



power tiller (B).

- Among the power tillers the vibration at the handle was higher by 72.94 to 170 percent for riding type power tillers.
- In field operation and transport mode the increase in forward speed of operation resulted in increased values of acceleration.
- The magnitude of vibration was higher at the handle (40.50 percent) and seat (28.08 percent) in untilled fields than tilled fields.
- In transport mode farm road induced higher vibration than bitumen road.
- Among the power tillers the vibration induced in walking type power tiller was higher during field operation whereas in transport mode power tiller (8.95 kW) exhibited higher values.

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