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Research Paper :

Effect of terrain conditions on vibration of power tillers

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ABSTRACT

Power tiller is a multi purpose hand tractor designed primarily for rotary tilling and other farm operations. This paper deals with machine vibration of walking and riding type power tillers during stationary mode as well as during rototilling in untilled and tilled fields and in transport mode on farm and bitumen roads. The results indicate that machine vibration increased with increase in engine speed and major excitation of the vibration of the power tiller was the unbalanced inertia force of the engine. In field operation and transport mode the increase in forward speed of operation resulted in increased values of acceleration. The magnitude of handle vibration was more in the untilled field than in the tilled field for both power tillers. The peak acceleration on the handle and underneath the seat was higher on farm road than in bitumen road (tar 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 with same trailer attachment.

Key words : Walking type power tiller, Riding type power tiller, Machine vibration

Among small and medium size category of power sources in agriculture farming, the hand tractor (also known as power tiller) is the most widely used equipment. Excessive vibration and noise level are the important shortcomings in power tiller design. In power tiller system, although the engine is the only source of excitation of vibration, its different moving parts vibrate at different frequencies depending on their own degree of freedom and natural frequencies which contribute to the further vibration of the whole system. This interference of vibration makes the vibration of the whole system rather complex.

Vibration affects human performance. 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). 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.

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). The low frequency vibration transmitted to the power tiller operator may affect vision, reaction time, physiological responses and emotional reactions (Kromer and Grandjean, 2000).

The magnitude of mechanical vibration at different components of the power tiller system under different terrain condition is essential for identifying the source of vibration and thereby providing vibration isolators to increase the safe exposure limit of operators. Thus, the present study measures machine vibration of two power tillers with one as walking type (7.46 kW) and the other as riding type (8.95 kW) during stationary mode as well as during rototilling in untilled and tilled fields and in transport mode on farm and bitumen roads at different forward speeds.

METHODOLOGY

The machine vibration was analysed using the portable multi-analyser system (Bruel and Kjaer Type 3560 C, Denmark). Vibration was measured using the Istron model 751-10 accelerometer. It is a low cost lightweight piezoelectric accelerometer with integral electronics designed specifically for measuring machine vibration in vertical direction. Its frequency response varies from 20 Hz to 20 kHz.

Two power tillers with one as walking type (Power tiller A) and the other as riding type (Power tiller B) were selected for the study, the technical specifications of which are furnished in Table 1.

The power tiller was subjected to proper test conditions before conducting the experiments. It was ensured that it was in full working order with full fuel tank and radiator, without optional front weights, tire ballast and any specialized components. Tyres used for the tests were of standard size and the depth of treads was not less than 70 % of the depth of a new tread. There were no known mechanical defects that would result in

Table 1 : Specification of the power tillers used for vibration measurements

Sr. No.	Details	Power tillers A	Power tillers B
1.	Engine type	Single cylinder, four stroke, water cooled, horizontal diesel engine	Single cylinder, four stroke, water cooled, horizontal diesel engine
2.	Rated crankshaft output	7.46 kW at 2400 min^{-1}	8.95 kW at 2000 min^{-1}
3.	Fuel tank capacity (l)	11	14
4.	Specific fuel consumption kg (kWh^{-1})	0.276	0.231
5.	Number of forward speeds	6	6
6.	Number of reverse speeds	2	2
7.	Number of rotavator speeds	4	4
8.	Forward speed range (km h^{-1})	1.75 – 15.0	1.4 – 15.3
9.	Reverse speed range (km h^{-1})	0.9 – 3.8	1.0 – 3.8
10.	Weight of power tiller (kg)	442	517
11.	Tyre size	6.00 × 12	6.00 × 12
12.	Tilling width (m)	0.60	0.60
13.	Number of tines in rotavator	18	18
14.	Tilling depth (m)	0.15	0.17
15.	Seating arrangement	Without seat	With seat

abnormal vibration.

Machine vibrations on the engine top, chassis, gear box, root of handle bar, handle and seat were measured for different engine speeds in the stationary condition for walking and riding type power tillers. Vibration levels on the root of handle bar and handle were measured for the walking type and on root of handle bar, handle and underneath the seat were measured in the case of riding type power tiller during rototilling in untilled and tilled fields. Vibration levels were also measured while riding with an empty trailer attachment during transport on farm and bitumen roads for both power tillers. The maximum vibration and pain to the body of the tractor operator occurred while riding the tractor with the empty trailer attachment on road (Balasankari, 1997). Hence, to measure the magnitude of vibration at the extreme condition, an empty trailer was used. During transport both power tillers were attached with the same trailer with an inbuilt cushioned seat. The riding seat (metal) and rear wheel of power tiller B (8.95 kW) were disconnected and attached to the cushion seated trailer. The recommended tyre pressures (147 kPa and 245 kPa) were maintained during rototilling and transport, respectively. Trails were repeated three times each with an acquisition period of 30 s and the peak rms value obtained from the spectrum was averaged for all operating conditions.

In the untilled condition, soil was left fallow after the harvest of the previous crop; and in the tilled condition, fallow land was ploughed twice with a tractor drawn cultivator before conducting the experiment. The soil was sandy clay with 49% clay, 41% sand and 9% silt. The surface condition of the untilled field was dry and undulating with a weed intensity of 0.37 kg m^{-2}. Similarly, the surface condition of the tilled field was dry with less undulation and without weeds. The soil moisture and bulk density measurements were up to 11% (d.b) and 1310 kg m^{-3} for the untilled field and 7% (d.b) and 1200 kg m^{-3} for the tilled field, respectively. Depth of operation was maintained at about 0.15 m. The surface condition of the farm road was dry, with less undulation and without weeds. The bitumen road was also dry, level and with medium surface finish without humps. Measurements were made at different forward speeds, *viz.*, 1.5 km h^{-1}, 1.8 km h^{-1}, 2.1 km h^{-1} and 2.4 km h^{-1} during field trials and 3.5 km h^{-1}, 4.0 km h^{-1}, 4.5 km h^{-1} and 5.0 km h^{-1} in transport mode.

RESULTS AND DISCUSSION

The findings of the present study as well as relevant discussion have been summarized under following heads:

Vibration characteristics at stationary mode:

The peak acceleration values arrived from the vibration spectrum for power tiller A at different engine speeds are presented in Table 2. It was observed that as the engine speed increases, the peak rms acceleration also increased at different locations. The results are in close agreement with studies conducted by Majumder,1994 and Mamansari, 1998 for a Thai-made power tiller.

The increase in engine speed from 900 to 2300 rpm

Table 2 : Machine vibration of power tiller A (walking type) 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 3 : Machine vibration of power tiller B (riding type) 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

resulted in two fold increase in vibration at engine top, nearly six fold increase at chassis, four fold increase at gear box, three fold increase at root of handle bar and two fold at handle of power tiller A.

Comparing the acceleration at the different locations of power tiller A, it is 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 is the unbalanced inertia force of the engine (Dong, 1996 and Ying *et al.*, 1998). The handles of the power tiller experienced higher acceleration because they were like cantilever beams subjected to force as well as free vibrations.

In case of power tiller B (Table 3), the increase in engine speed from 900 to 2000 rpm resulted in three fold increase in vibration at engine top and two fold increase at handle.

Acceleration on the seat was also high because it was mounted on the telescoping shaft that adjusts the depth. The result indicate that the riding type power tiller showed higher values of acceleration at all locations compared to the walking type power tiller at the same engine speed and was mainly attributed to the higher rated engine power of the riding type power tiller.

Vibration characteristics in rototilling operation:

The highest value of acceleration arrived from the vibration spectrum for power tiller A at selected forward speeds in untilled and tilled field are furnished in Table 4.

It was observed that the magnitude of acceleration

Table 4 : Machine vibration of power tiller A during rototilling

Forward speed ($km\ h^{-1}$)	Peak acceleration, $m\ s^{-2}$			
	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

on the root of the handle bar and handle increased with increase in selected levels of forward speed in both untilled and tilled fields. 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 field. It was seen that the rototilling in the untilled field resulted in 48 per cent more handle vibration than rototilling in the tilled field. Since the untilled field was dry, rough and compact, the damping effect was less. Also the presence of root stalks of previous crops and biting of tines on hard soil might add vibration to the system. This indicated the effect of terrain induced vibration through wheels (Clijmans *et al.*,1998).

In the case of riding type power tiller (Table 5), it is inferred that the increase in forward speed from 1.5 to 2.4 km h^{-1} resulted in an increased peak value of acceleration by 91.6 per cent at the root of handle bar, 46.12 per cent at handle and 104 per cent at seat in untilled field.

The peak acceleration on the handle and underneath

Table 5 : 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 6 : 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 7 : 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

the seat was higher in untilled filed than in tilled field as observed in power tiller A. Comparison between handle vibrations of walking and riding type power tillers during rototilling showed that acceleration values were higher for power tiller A than power tiller B both in untilled and tilled field. The peak rms acceleration at 2.4 km h^{-1} was 18.10 m s^{-2} for the walking type during rototilling in the untilled field whereas for the riding type it was 7.35 m s^{-2} in the untilled field.

Vibration characteristics in transporting operation:

In transport mode of power tiller A (Table 6), the increase in peak acceleration at handle was 30 per cent and underneath the seat was 90 per cent with the increase in forward speed from 3.5 to 5.0 km h^{-1} on farm road.

In case of power tiller B, values of acceleration on the handle and underneath the seat were increased by 36.17 and 47.69 per cent (Table 7). The peak acceleration was higher on the farm road than on the bitumen road, the increase being 25 per cent for power tiller A and 31 per cent for power tiller B at the forward speed of 5 km h^{-1}. This might be due to unevenness and moderate undulations on farm roads compared to relatively even and medium surface finish level on bitumen roads. The results showed that during transport mode, magnitude of vibration intensity at the handles and underneath the seat were higher for the riding type power tiller than the walking type, the increase being 97 per cent and 17 per cent on the farm road and 87 per cent and 57 per cent on the bitumen road, respectively, at the forward speed of 5 km h^{-1} .

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 the riding type power tiller was higher than the walking type.

Conclusion:

Vibration levels depend on the terrain conditions and engine speed of the power tiller. It was observed that as the engine speed increases, rms acceleration also increased and it was highest on the top of the engine. The magnitude of handle vibration was more in the untilled field than in the tilled field for both power tillers. The peak rms acceleration at 2.4 km h^{-1} was 18.10 m s^{-2} for the walking type during rototilling in the untilled field whereas for the riding type it was 7.35 m s^{-2} in the untilled field. The trend of the vibration intensity for transportation was the same as that of rototilling. The results showed that during transport mode, magnitude of vibration intensity at the handles and underneath the seat were higher for the riding type power tiller than the walking type, the increase being 97 per cent and 17 per cent on the farm road and 87 per cent and 57 per cent on the bitumen road, respectively, at the forward speed of 5 km h^{-1}.

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