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Study of Vibration Exposure from 55 HP Agricultural Tractors in Rotary Tillage Operations

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ABSTRACT

Tractor is a versatile vehicle designed to deliver high torque at much lower speed. It is mainly used for off-road condition and different field operations. Among these, rotavators are getting popularised as it can be used for both primary and secondary tillage operation as well as both in wet land and dry land operations. It has the capability of producing good quality tillage compared to other tillage operations. However, the impact action of rotavator blades generate very intense vibrations. These vibrations when transmitted to the operator may cause various musculoskeletal disorders. Hence, to evaluate this a study was conducted to evaluate the effect of tractor use hour, operator weight, speed of operation and depth of operation on whole body vibration and hand arm vibration. From the study it was found that, with increase in hours of use vibration increased. The vibration was found lower in 75 kg operator as compared to 65 kg and 85 kg operators. Both whole body vibration and hand arm vibration was observed to be increased with increase in speed of operation. However, the effect of depth of operation was not increased linearly with increase in depth of operation.

Introduction

Tractor is a versatile vehicle designed to deliver high torque at much lower speed. It is mainly used for off-road condition and different field operations starting from land preparation to harvesting of produces. In India, tractor is mostly used for land preparation by using mould board plough, disc plough, rotavator etc. Among these, rotavators are getting popularised as it can be used for both primary and secondary tillage operation as well as both in wet land and dry land operations. It has the capability of producing good quality tillage compared to other tillage operations (Prakash *et al.*, 2013). The tractor operated machines creates vibration and rotavator is of no exception (Mehta *et al.*, 1997). The rotavator blades cuts the soil slice by impact action or slicing action depending on the design of the blades. This generates very intense vibration which is then transmitted to the operator through various parts like seat suspension, steering wheel, sitting platform, hand control knobs etc (Village *et al.*, 2012). The important factors that has significant effect on vibration are forward speed of tractor and uneven ground condition (Oude vrielink, 2009). Among the different form of vibration generated, the vibration transmitted to the operators' body to the seat from the feet via the chassis and to the hand arm system from the steering wheel (Goglia *et al.*, 2003). Tractor operation becomes more critical at the frequency range 1 – 7 Hz as resonance occurs in between these frequency ranges (Kumar *et al.*, 2001). These frequency range may cause musculoskeletal disorders among the operators mostly in the back region of the operators (Prakash *et al.*, 2013). The occupational low back pain is predominant among the tractor operators due to exposure of whole body vibration (Boshulzen *et al.*, 1990). Hand arm vibration may cause damage to fingers i.e. white finger diseases, numbness and carpel tunnel syndrome (Griffin, 1996). From evaluation and analysis of the ride comfort during soil tillage operation, it was found that the forward speed of operation has greater impact on vibration transmission to the operator (Singh *et al.*, 2019). Another study confirmed that, the effect of vibration is predominant for rotavator operation compared to soil tillage operations (Dewangan *et al.*). During ploughing condition, the hand arm vibration in frequency range of 1-20 Hz and 40 -80 Hz was found to have very critical effect on operator (Zaka *et al.*, 2015). Very few research work was done in effect of vibration during rotary tillage operation. Hence, the present study focuses on the effect of speed of operation and depth of operation on both hand arm vibration and whole body vibration and also the effect of operator's weight on whole body vibration.

Materials and Methods

Field condition

The field experiments were conducted in the field available in Central Farm of Odisha University of Agriculture and Technology, Bhubaneswar. Two fields were selected for the study one for dry tillage and another for wet tillage. To evaluate the effect of speed of operation and depth of operation, three different levels of each parameter were selected. Table 1 shows the selected speed of operation and depth of operation for rototilling operation in both fields. The recommended speed of operation was 3 kmph and 2 kmph during dry tillage and wet tillage operation, respectively. Hence, the speed of operation selected were one level above and below the recommended speed. Similarly, the recommended depth of operation was 12 cm and 15 cm for dry and wet field operation, respectively. Hence the depths selected were 8 cm, 12 cm and 16 cm for dry field and 12 cm, 15 cm and 18 cm for wet field operation.

Selection of tractor and rotavator

Two 55 hp PTO power tractors available in Odisha University of Agriculture and Technology were selected for the vibration study. They were selected in such a way that the effect of hours of use on vibration can be evaluated. The first tractor selected was new one with hours of use less than 50 hours whereas the other tractor had more than 5000 hours of use. Fig. 2 shows the tractors selected for the study. The detailed specifications of the tractors are shown in Table 2. Both the tractors were fitted with 1.2 m width rotavator. The detailed specifications of the rotavator is presented in Table 3.

Selection of subjects

The tractor seat was designed to seat operator's weight of 50 to 120 kg. Hence, three operators were selected in the weight range 60-70 kg, 70-80 kg and 80-90 kg. The operators were selected to evaluate the effect of operators' weight on vibration. Table 4 shows the weight, height, body surface area (BSA) and body mass index (BMI) of the selected operators.

Vibration measurement

For vibration measurement, accelerometer was used. The complete setup includes accelerometer, module, battery and data acquisition system. The complete setup is shown in Fig 3. The detailed specification of the tri-axial accelerometer is given in Table 5. The used accelerometer was apiezo-resistive type. The sensing element consists of a very small mass and a flexure element cantilevered between two plates. Due to vibration, the deflected mass impacts a force which was measured by strain gauge. The AC excitation and amplitude demodulation circuit present in the accelerometer gives an analogue voltage output that is proportional to the applied acceleration. The output signal from accelerometer acts as input for the NI 9215 module where the signals were converted to acceleration values. The module was connected to a data acquisition system through a USB cable. The data were collected by using DEWESOFT software interface where 5000 vibration data were collected per second. To measure the transmitted whole body vibration, first the accelerometer was placed above the seat cushion of tractor seat. Similarly, to measure hand arm vibration transmitted through steering wheel, the accelerometer was attached to the steering wheel firmly. Fig 4 shows the accelerometer locations for vibration measurement. For each condition of vibration measurement, ten numbers of replications were done.

Vibration analysis

The vibration data was analysed as per ISO 2631:1991 and ISO 5349-1:2001. First peak data were collected in time domain and then it was converted to frequency domain by fast fourier transform. The peak data were converted to RMS acceleration data. The frequency domain data was again converted to 1/3rd octave band data and human weightage was applied as given in the above mention standards. To calculate the overall weighted vibration, the data selected for whole body vibration was 1-80 Hz and that for hand arm vibration were 50-1000 Hz. Then the overall weighted vibration data was calculated by the formula given below.

$$a_{wi}=\sum a_i W_i^2$$

$$a=\sqrt{(k_x a_{wx})^2+(k_y a_{wy})^2+(k_z a_{wz})^2}$$

Where

a_{wi} = weighted RMS acceleration

a_i = RMS acceleration in ith frequency

W_i = weightage of ith frequency

a_{wx}, a_{wy} and a_{wz} = weighted RMS acceleration in x, y and z axis, respectively

a = overall acceleration

k_x, k_y and k_z = multiplying factors

$k_x, k_y = 1.4$ and $k_z = 1$ for whole body vibration

k_x, k_y *and* $k_z = 1$ for hand arm vibration

n, k = limits of vibration

i = 0.5 to 80 Hz for whole body vibration and
i = 50 to 1000 Hz for hand arm vibration

Limits of whole vibration exposure

As per EU DIRECTIVE 2002/44/EC, for better performance of the operator, the limit of whole body and hand arm vibration exposure should not be exceeded as the value given below. Exposure action value (EAV) is defined as the level of daily exposure set out for any worker if exceeded, then the necessary action should be taken to reduce the risk and exposure limit value is defined as the level of daily exposure that should not be exceeded

Results and Discussion

The whole body vibration and hand arm vibration was measured during rotavator operation in dry field condition and wet field condition. To evaluate the effect of operator's weight, speed of operation and depth of operation, the tractors were tested at three different levels for each of the following parameters. For each condition four numbers of replication were done. Table 7 shows the ANOVA (Analysis of Variance) of the measured WBV data. In the table factor A, B, C, D and E represents terrain type, tractor type, speed of operation, operator's weight and depth of operation, respectively. From the table it can be clearly seen that, the main effect of factors B, C and D on WBV were significantly different at both 5 per cent and 1 per cent level of significance whereas that of factor A and E were significantly different at only 5 per cent level of significance. All the interaction effects were significantly different at both 5 per cent and 1 per cent level of significance except those where factor A and E were on the parameter. In those levels, they were significantly different at only 5 per cent level of significance. While considering multiple interactions, the data were significantly different at both level of significance.

Table 8 shows the ANOVA result of the HAV. Here the main factors were terrain type (A), tractor type (B), speed of operation (C) and depth of operation (E). Here, the operator's weight was not a parameter as there is no effect of this on HAV. From the table it can be clearly seen that the main effect of factor B and C was significantly different at both 5 per cent and 1 per cent level of significance whereas that of factor A and E was significantly different at only 5 per cent level of significance. Similarly, as in WBV, the interaction effects were significantly different both 5 and 1 per cent level of significance except those where factor A and factor E were one the interaction parameter.

Effect of speed of operation on vibration

Overall weighted RMS vibration acceleration for both WBV and HAV was found to be increased with increase in speed of operation, which is shown in Table 9. In both field, with increase in speed of operation, the WBV and HAV was found to be increased significantly which was due to increased occurrence of ground undulation at higher speed. However, the percentage increase in vibration was higher in dry field as compared to wet field operation which may be due to the more cushioning effect of wet field as compared to dry field. This was because of presence of standing water and higher moisture content of the wet soil. With increase in speed of operation, the overall weighted WBV for tractor 1 increased from 1.10 m/s^2 to 1.42 m/s^2 with a percentage increase of 29.09 per cent for dry field and 0.97 m/s^2 to 1.22 m/s^2 with a percentage increase of 25.77 per cent. For tractor 2, it was increased from 1.39 m/s^2 to 1.62 m/s^2 with a percentage increase of 16.54 per cent in dry field and 1.17 m/s^2 to 1.31 m/s^2 with a percentage increase of 11.96

per cent. Similarly, the HAV in tractor 1 increased from 2.53 m/s^2 to 3.30 m/s^2 with a percentage increase of 30.43 per cent in dry field and 2.42 m/s^2 to 2.93 m/s^2 with a percentage increase of 21.07 per cent in wet field.

Effect of depth of operation on vibration

Overall weighted RMS vibration acceleration for both WBV and HAV was observed to be decreased with increase in depth of operation in dry field as well as wet field rototilling operation (Table 10). This was due to increase depth of operation increase load on the rotavator blades as well as on the tractor. As a result, the tractor parts vibrates less at higher depth and less vibration was transmitted to the operator seat as well as to steering wheel of tractor. With increase in depth of operation, the overall weighted WBV for tractor 1 decreased from 1.29 m/s^2 to 1.09 m/s^2 with a percentage decrease of 15.50 per cent for dry field and 1.16 m/s^2 to 0.98 m/s^2 with a percentage decrease of 15.51 per cent. For tractor 2, it was decreased from 1.54 m/s^2 to 1.31 m/s^2 with a percentage decrease of 14.93 per cent in dry field and 1.27 m/s2 to 1.08 m/s2 with a percentage decrease of 14.96 per cent. Similarly, the HAV in tractor 1 decreased from 2.63 m/s^2 to 2.29 m/s^2 with a percentage increase of 12.92 per cent in dry field and 2.54 m/s^2 to 2.15 m/s^2 with a percentage decrease of 15.35 per cent in wet field. For tractor 2, HAV was observed to be decreased from 2.92 m/s^2 to 2.42 m/s^2 with a percentage decrease of 16.43 per cent in dry field and 2.84 m/s^2 to 2.37 m/s^2 with a percentage decrease of 16.54 per cent.

Effect of operators' weight on vibration

Table.11 shows that with increase in operator's weight, the vibration value increases but not linearly as the vibration value was more for operator of weight 85 kg than 75 kg but it was more in 65 kg than 75 kg operator. This pattern of vibration was observed for both the tractor during dry field as well as in wet tillage operation. For 65 kg operator, the seat suspension acts as hard surface and transmit the vibration to the operator seat without any reduction. But for 85 kg operator, the seat suspension behaves like soft medium which takes more time to dampen the vibration and increases the amount of vibration transmitted to the operator. In tractor 1, the overall weighted RMS vibration acceleration was found to be 1.19 m/s^2, 1.10 m/s^2, 1.34 m/s^2 in dry field and 1.08 m/s^2, 0.93 m/s^2 and 1.14 m/s^2 in wet field for 65 kg, 75 kg and 85 kg operator, respectively. Similarly, while rototilling operation with tractor 2, the WBV was found to be 1.30 m/s^2, 1.24 m/s^2, 1.47 m/s^2 in dry field and 1.16 m/s^2, 1.10 m/s^2, 1.34 m/s^2 in wet field for 65 kg, 75 kg, 85 kg operator, respectively.

Effect of number of hour use of tractor and field conditionon vibration

Fig 8 shows the vibration value in both the tractor during dry tillage and wet field operation. In dry field, the soil cone index was found to be 100 kPa whereas for wet field it was less than 20 kPa. The wet field had also standing water of depth around 10 cm. Hence, during rotavator operation in wet field, some of blade generated vibrations was absorbed by the standing water and soft soil. This results in less vibration transmitted to the operator in wet field as compared to dry field where the soil was harder one. From fig.8, it was found that tractor 1 transmit more vibration as compared to tractor 2. The hours of use of tractor 2 was more than 5000 hours whereas that of tractor 1 was less than 200 hours. With increase in hours of use, some parts of the tractor get worn out, which creates more vibratory motion and transmit more vibration to the operator. In dry field operation, the

WBV was found to be 1.34 m/s^2, 1.65 m/s^2 and HAV was 3.23 m/s^2, 3.48 m/s^2 for tractor 1 and tractor 2, respectively. Similarly, in wet field operation, the WBV was 1.21 m/s^2, 1.47 m/s^2 and HAV was 2.98 m/s^2 and 3.29 m/s^2 for tractor 1 and tractor 2, respectively.

Table.1 Field condition, speed and depth of operation

Field condition	Speed, kmph			Depth, cm		
Dry field	2 (S_{d1})	3 (S_{d2})	4 (S_{d3})	8 (D_{d1})	12 (D_{d2})	16 (D_{d3})
Wet field	1 (S_{w1})	2 (S_{w2})	3 (S_{w3})	12 (D_{w1})	15 (D_{w2})	18 (D_{w3})

Table.2 Specification of tractors selected for the study

	Tractor 1	Tractor 2
Make	John Deere (JD)	New Holland (NH)
Model	5310	5500
Rated power, kW	55	55
Number of hour use, h	1056	116
Number of cylinder	3	3
Rated rpm	2400	2300
Air filter	Dry air cleaner	Dry air cleaner
Clutch	Synchromesh	Constant mesh, partial synchromesh
Gear box	9F+3R	8F + 2R
Brake	Oil immersed multi disc	Oil immersed multi disc brake
Steering	Power	Power
PTO type	Multi speed PTO	Ground speed PTO
PTO rpm	540	540
Fuel tank capacity, L	68	63
Weight,kg	2110	2220
Wheel base, mm	2050	2055
Overall length, mm	3535	3500
Overall width, mm	1850	1925
Ground clearance, mm	435	470
Hydraulic lifting capacity, kg	2000	2400
Drive	2 WD	4 WD
Front tyre	6.5 X 20	9.25 X 16
Rear tyre	16.9 X 28	16.9 X 28

Table.3 Specification of rotavator

Make	**Maschio gasoardo**
Model	Virat v185
Power of tractor	30 -75 hp
Blade type	L- type
Rpm of gear box	540
Weight	550 kg
Working width, mm	160 to 185
Working depth, mm	120 to 17.5
Speed	Multi speed
Type of drive	Gear
Number of blades	42

Table.4 Physiological parameter of operators selected for the study

Particulars	**Operator 1**	**Operator 2**	**Operator 3**
Weight, kg	65	75	85
Height, cm	165	158	162
BSA, m^2	1.38	1.57	1.78
BMI, kg/m^2	39.85	41.40	42.13

Table.5 Detailed specification of Tri-axial accelerometer

Make	**Bruel and Kjaer**
Mass, g	30
Frequency range, Hz	0-1000
Measurement range	50 g (g=9.81 m/s^2)
Temperature range, ^{0}C	-55 to 125
Sensitivity, g/v	0.002

Table.6 Vibration exposure limits as per EU Directive

	Whole body vibration	**Hand arm vibration**
EAV	0.5 m/s^2	2.5 m/s^2
ELV	1.15 m/s^2	5 m/s^2

Table.7 ANOVA result of WBV data during rotavator operation

Sources of variation	Degree of freedom	Mean square	F-value	P value
A	1	0.000	4.86	0.021
B	1	0.287	2258.34	0.000
C	2	0.013	44.98	0.000
D	2	0.035	591.60	0.000
E	2	0.000	3.83	0.035
A X B	1	0.000	3.48	0.031
A X C	2	0.000	4.36	0.013
A X D	2	0.000	3.54	0.027
A X E	2	0.000	4.52	0.018
B X C	2	0.053	982.52	0.000
B X D	2	0.048	987.13	0.000
B X E	2	0.341	3259.78	0.000
C X D	4	0.005	248.98	0.000
C X E	4	0.026	52.30	0.000
D X E	4	0.037	836.08	0.000
A X B X C	2	0.000	7.83	0.000
A X B X D	2	0.002	13.68	0.000
A X C X D	4	0.000	5.87	0.002
B X C X D	4	0.035	649.00	0.000
A X B X C X D	4	0.000	9.61	0.000
A X B X C X D X E	8	0.000	12.98	0.000
Error	51			

Table.8 ANOVA result of HAV data during rotavator operation

Sources of variation	Degree of freedom	Mean square	F-value	P value
A	1	0.000	4.86	0.021
B	1	0.287	2258.34	0.000
C	2	0.013	44.98	0.000
E	2	0.000	3.83	0.035
A X B	1	0.000	3.48	0.031
A X C	2	0.000	4.36	0.013
A X E	2	0.000	4.52	0.018
B X C	2	0.053	982.52	0.000
B X E	2	0.341	3259.78	0.000
C X E	4	0.026	52.30	0.000
D X E	4	0.037	836.08	0.000
A X B X C	2	0.000	7.83	0.000
A X B X C X E	4	0.000	9.613	0.000
Error	7			

Table.9 Effect of speed of operation on vibration

		Dry field, m/s^2				Wet field, m/s^2			
	Speed, kmph	**(S_{d1})**	**(S_{d2})**	**(S_{d3})**	**% increase from S_{d1} to S_{d3}**	**(S_{w1})**	**(S_{w2})**	**(S_{w3})**	**% increase from S_{w1} to S_{w3}**
T_1	**WBV**	1.10	1.24	1.42	29.09	0.97	1.12	1.22	25.77
	HAV	2.53	2.69	3.30	30.43	2.42	2.53	2.93	21.07
T_2	**WBV**	1.39	1.30	1.62	16.54	1.17	1.25	1.31	11.96
	HAV	2.98	3.12	3.45	15.77	2.83	2.97	3.18	12.36
d – dry field operation, w-wet field operation									

Table.10 Effect of depth of operation on vibration

		Dry field, m/s^2				Wet field, m/s^2			
	Depth, cm	**(D_{d1})**	**(D_{d2})**	**(D_{d2})**	**% decrease from D_{d1} to D_{d3}**	**(D_{w1})**	**(D_{w2})**	**(D_{w3})**	**% decrease from D_{w1} to D_{w3}**
T_1	**WBV**	1.29	1.17	1.09	15.50	1.16	1.10	0.98	15.51
	HAV	2.63	2.57	2.29	12.92	2.54	2.31	2.15	15.35
T_2	**WBV**	1.54	1.37	1.31	14.93	1.27	1.18	1.08	14.96
	HAV	2.92	2.79	2.44	16.43	2.84	2.70	2.37	16.54
d- dry field operation, w- wet field operation									

Table.11 Effect of weight of operator on vibration

	Dry field, m/s^2			Wet field, m/s^2		
	65 kg	**75 kg**	**85 kg**	**65 kg**	**75 kg**	**85 kg**
T1	1.19	1.10	1.34	1.08	0.93	1.14
T2	1.30	1.24	1.47	1.16	1.10	1.34

Table.12 Values of limit fatigue according to ISO 2631: 1991

Field condition	Tractor type	Operator weight, kg	Limit fatigue, h
Dry field	**Tractor 1**	65	4
		75	4
		85	4
	Tractor 2	65	4
		75	4
		85	4
Wet field	**Tractor 1**	65	4
		75	4
		85	4
	Tractor 2	65	4
		75	4
		85	4

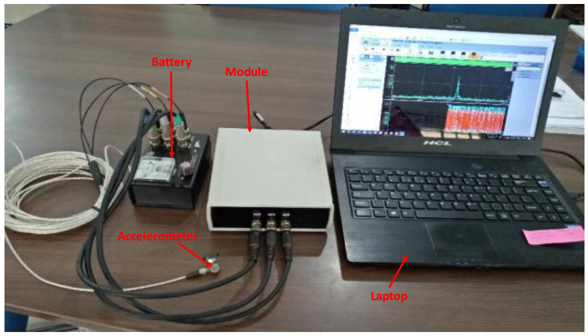
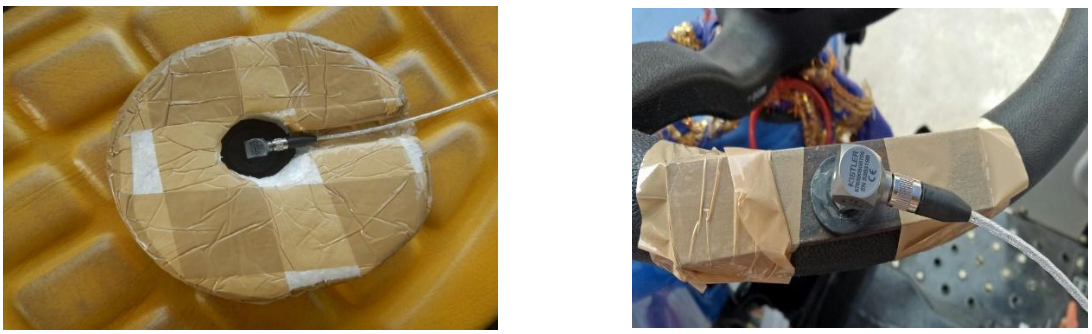


Fig.3 Vibration measurement set up



A B

Fig.4 Accelerometer location for vibration measurement on a) seat cushion b) steering wheel

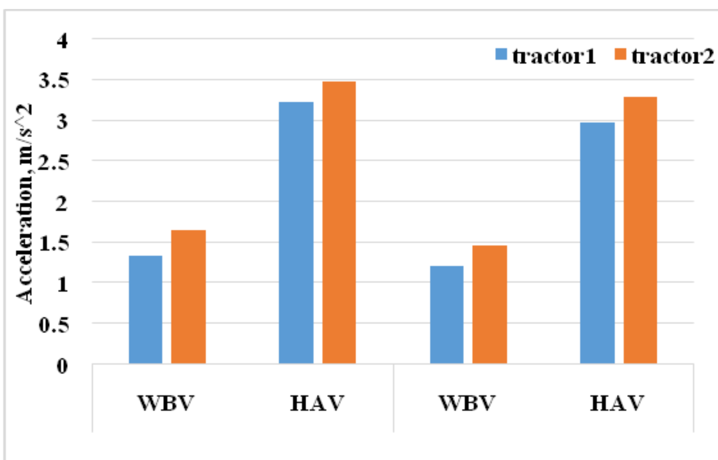


Fig 8.WBV and HAV in tractor 1 and tractor 2 during dry and wet field operation

The overall weighted RMS acceleration values were calculated as per ISO 2631:1991 for both WBV and HAV. For WBV, the vibration data collected was in the frequency range 1-80 Hz whereas for HAV the data collected was in the frequency range 1-1500 Hz. When these vibration values were compared with 8h exposure value which defines the equal fatigue decreased proficiency boundaries, it was found that the fatigue hour for all treatments were within 4 hours (Table 12).

It is concluded, by using rotavator, both primary and secondary tillage operation can be done simultaneously. Due to striking of rotavator blades at higher speed,vibration is transmitted to the operator through steering wheel and seat suspension. Hence, the objective of the study was decided to evaluate the whole body vibration and hand arm vibration during dry field and wet field operation. For this two tractors of same rated power, available at Odisha University of Agriculture and Technology, Bhubaneswar was selected. To analyse the effect of operator weight, three operators of weight 65 kg, 75 kg and 85 kg were selected for driving operation. Similarly, to evaluate the effect of speed of operation on vibration, three different speed of operations was selected for the study. During the test, the overall weighted RMS acceleration was analysed in $1/3^{rd}$ Octave band for WBV (1-80 Hz) and HAV (50-1000 Hz). The results of the tests were the following:

1. With increase in speed of operation, the overall weighted RMS acceleration for both WBV and HAV were observed to be increased proportionally.
2. With increase in depth of operation, the overall weighted RMS acceleration values for both WBV and HAV were decreased significantly.
3. The overall weighted WBV was found to be less in case of 75 kg operator followed by 85 kg and 65 kg operator.
4. For dry field operation with rotavator, the WBV and HAV values were on higher side as compared to wet field operation.
5. While comparing the tractor of same rated power, the vibration values for both WBV and HAV was observed to be higher in case of tractor with higher hours of use.
6. The limit fatigue for all treatments were found to be within 4 hours while comparing with equal fatigue decreased proficiency boundaries for both WBV and HAV.

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