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Technical note

Ride vibration on tractor-implement system

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Abstract

India is the largest manufacturer of tractors in the world. They are used for primary and secondary tillage operations and as a means of transportation. Vibration in tractor driving can cause deafness and disorders of the spinal column and stomach. The effect of implements on tractor ride is not well understood in India. The present study was undertaken to quantify ride vibration of a low horsepower tractor-implement system. Tractor ride vibration levels have been measured at the person–seat interface along three mutually perpendicular axes, longitudinal, lateral and vertical, under different operating conditions. It was observed that the acceleration levels increased as forward speed of travel increased under most of the operating conditions. There was no conclusive difference in measured acceleration levels on a tar-macadam road and a farm road during transport mode. The measured ride vibration levels under different operating conditions were evaluated as per ISO 2631/1 (1985), Geneva, and BS 6841 (1987), London, standards. On the basis of this study, it is concluded that the exposure time for the tractor operator should not exceed 2.5 h during ploughing and harrowing operations. Increasing exposure time may cause severe discomfort, pain and injury.

Keywords: Tractor; Ride vibration; Operator comfort

1. Introduction

India is the largest world market for tractors below 37 kW, due to the small size of land holdings. The current population of tractors in India is around 1.5 millions and more than 0.15 million tractors are added to Indian agriculture every year. They are being mainly used for primary and secondary tillage operations and as a means of transportation to haul goods, people and even animals.

With the high degree of mechanisation of farms along with increasing size and complexity of farm machinery, a safe comfortable working environment for the operator becomes an important consideration if productivity and customer satisfaction are to be enhanced (Gerke and Hoag, 1981). The occupational hazards of tractor driving include deafness and disorders of the spinal column and stomach, caused by vibration. Besides, these also result in lower work output and quality. In view of the deterioration in health and working efficiency attributed, at least in part, to the ride vibration, it is highly desirable for the seat to attenuate vehicle vibration as much as possible (Matthews, 1964). Most of the past work on tractor dynamics in India has considered only the tractor in attempts to investigate ride characteristics. However, the tractors are normally operated with either an implement or a trailer (Crolla, 1976). Neither the effect of implements on tractor ride vibration is well understood, nor is the effect of tractor ride vibration on operator's effectiveness and heath. The present study was undertaken to quantify the effect of the tractor-implement system on tractor ride vibration. The data have been analysed so that safe exposure limits can be recommended, keeping in view the limits set by the International Standards Organisation and the British Standard.

2. Material and methods

A 26 kW two wheel drive tractor (three cylinder, 4-stroke, water cooled, DI diesel engine) available in the Agricultural Energy and Power Division at the Central Institute of Agricultural Engineering, Bhopal (India) was selected for this study (Mehta, 1992). The tractor was

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brought in proper test condition (ISO 5008,1979) before conducting the experiments. The tractor was in working order with full tank and radiator, without optional front and rear wheel weights, liquid ballast in the tyres and any auxiliary equipment. Tyres used for the tests were of standard size and depth of tread was not less than 65% of the depth of new tread. The recommended tyre pressures of 172 kPa in front tyres (152.4 – 406.4 mm) and 147 kPa in rear tyres (315.0 – 711.2 mm) during transport mode and 172 kPa in front tyres and 79 kPa in rear tyres during field operations were maintained. The seat mounted on the tractor had four bar linkage type suspension with two helical tensile springs (spring constant 11.3 N/mm) and a hydraulic damper (damping coefficient 0.920 N-s/mm) in parallel. One operator of normal physique and mass (58 kg) was used throughout these tests.

Ride vibration was measured by a human vibration unit type 2522 attached to the modular precision sound level meter type 2231, using human vibration module BZ 7105 (Bruel and Kjaer, Denmark). Triaxial seat accelerometer type 4322 (Bruel and Kjaer) was used as a transducer. The triaxial seat accelerometer was mounted on the operator's seat at a point on the interface between the operator and his seat to measure ISO weighted r.m.s. acceleration levels along three mutually perpendicular axes, vertical (a_z), longitudinal (a_x) and lateral (a_y) as per International Standard (ISO 2631/1, 1985). The precision sound level meter was frequency weighted for the frequency range of 1–80 Hz with an electronic network, so that its vibration response characteristics closely matched the response of the human body and it provided an average normalised ride vibration over a test period from 23 to 340 s.

The tests were conducted on three different surfaces, a tar-macadam road, a farm road and an untilled field during the transport mode of the tractor alone, on an untilled field during the transport mode and the ploughing operation for the tractor with two bottom MB plough, and on a tilled field during transport mode and the harrowing operation for the tractor with offset disc harrow. The surface conditions of terrains used during transport mode and during ploughing and harrowing operations are given in Table 1.

Measurements were made at different throttle settings and in different gears to obtain desired forward speed of travel during transport mode, ploughing and harrowing operations. The forward speed of travel was measured by timing the tractor between marks at the beginning and end of a 100 m test run during transport mode and 60 m test run during field operations.

The measured ride vibration levels under different operating conditions were compared with the values specified under International Standard (ISO 2631/1, 1985) and given in the frequency bands of 4–8 Hz for vertical (a_z) and SUM and 1–2 Hz for longitudinal (a_x) and lateral (a_y) axes in relation to working efficiency and health and safety of the operator. The 8, 4 and 2.5 h exposure limits as per International Standard (ISO 2631/1, 1985) are compared with the acceleration levels measured at various forward speeds. The vibration dose values (VDV) for a work day exposure (8 h duration) were also calculated as per British Standard (BS 6841, 1987).

3. Results and discussion

Figs. 1 and 2 show the variation of ISO weighted r.m.s. acceleration level with forward speed during transport mode of the tractor alone under different track conditions and during transport mode and field operations on the tractor-implement system under different operating conditions, respectively. The 8, 4 and 2.5 h exposure limits (ISO 2631/1,1985) are superimposed on these figures.

It was observed that ISO weighted r.m.s. acceleration levels in longitudinal, lateral and vertical axes increased with the increase in forward speed of travel under all the track and operating conditions. The measurements of ride vibration were made at a slightly higher speed during the transport mode for the tractor alone than for the tractor-implement system because of lower wheel slip. The ride vibration levels in the vertical axis were the highest.

Table 1
Terrains used for ride vibration measurements

Mode of operation	Terrains	Soil moisture (db),%	Bulk density, g/cm^3	Remarks
Transport	Tar-macadam road	—	—	Dry, level, medium surface finish
	Farm road	—	—	Dry, level, small undulations without weeds
	Untilled field	18.85	1.735	Dry, undulating, 5–10 cm high stubbles
	Tilled field	17.58	1.55	Dry, undulating and without weeds
Ploughing	Untilled field	18.85	1.735	Dry, undulating, 5–10 cm high stubbles
Harrowing	Tilled field	17.58	1.55	Dry, undulating and without weeds

4. Ride vibrations on tractor alone

Fig. 1 shows that ISO weighted r.m.s. acceleration levels in all the axes were the highest on the untilled field and the least on the tar-macadam road for the same speed of travel. On tar-macadam and farm roads, no conclusive differences in lateral, vertical and SUM acceleration levels were found during the transport mode. This may be due to the poor surface condition of the tar-macadam road. The increase in r.m.s. acceleration levels was gradual on tar-macadam and farm roads and steep on the untilled field with forward speed of travel.

In the vertical axis, the higher vibration intensities were encountered at high speed over all terrains. It suggests that vibrations arose more from repeated transient oscillations of the vehicle than from transmission of actual ground irregularities. The vibration levels in vertical and longitudinal axes on tar-macadam road and in longitudinal axis on farm road were within the 2.5 h exposure limit. The vibration levels exceeded the 2.5 h exposure limit at forward speeds of 2.78 m/s on the farm road in vertical axis and at 0.86, 1.28 and 1.43 m/s on the untilled field in longitudinal, lateral and vertical axes, respectively (Fig. 1).

The SUM vibration levels on the untilled field were 2–2.5 times higher than those on tar-macadam and farm roads. The SUM acceleration levels exceeded the 2.5 h exposure limit on tar-macadam road, farm road and untilled field at forward speeds of 1.49,1.47 and 0.69 m/s,

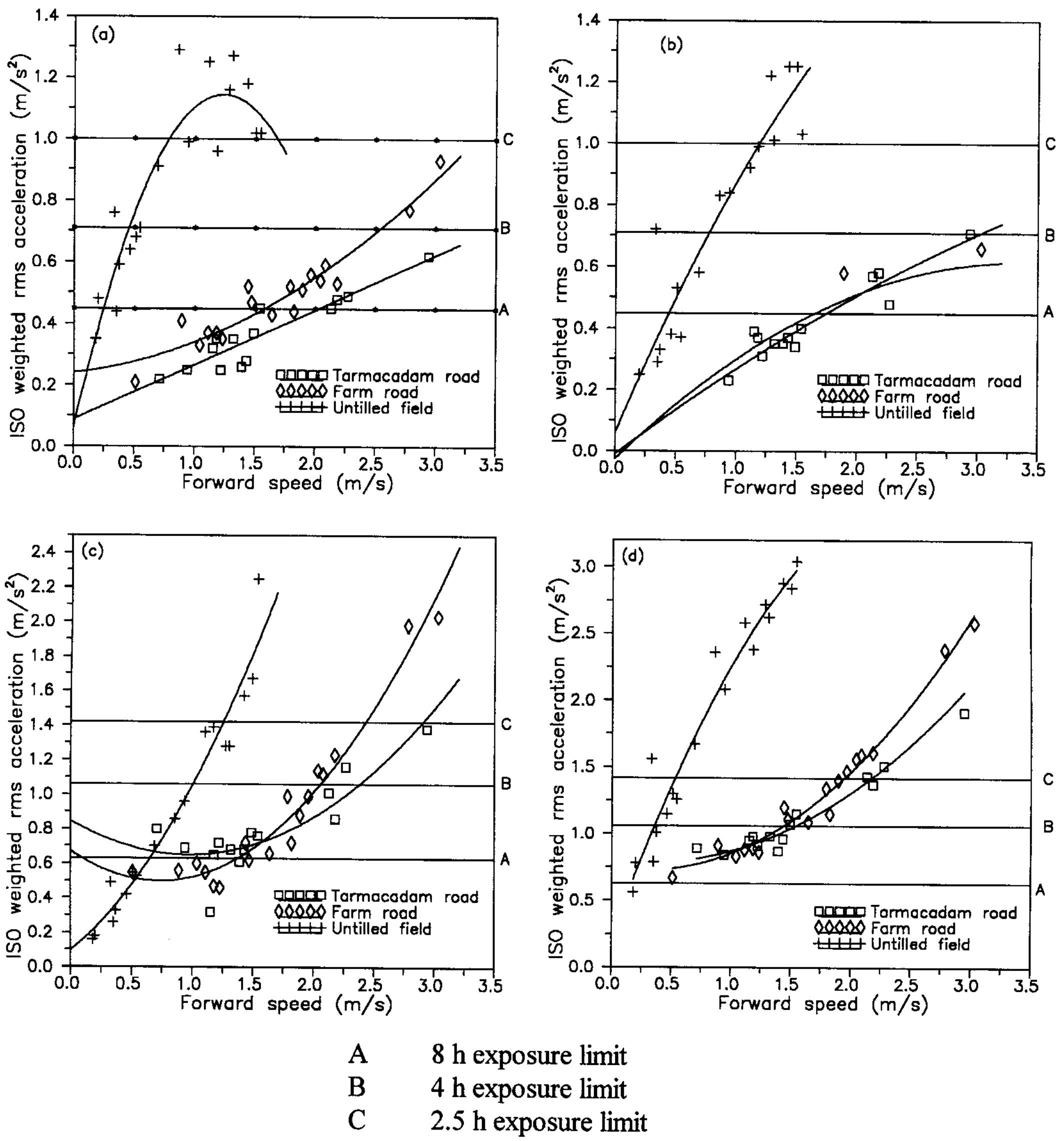

Fig. 1. Variation of acceleration level with forward speed during transport mode of the tractor: (a) Longitudinal acceleration level (a_x). (b) Lateral acceleration level (a_y). (c) Vertical acceleration level (a_z). (d) Sum acceleration level (SUM).

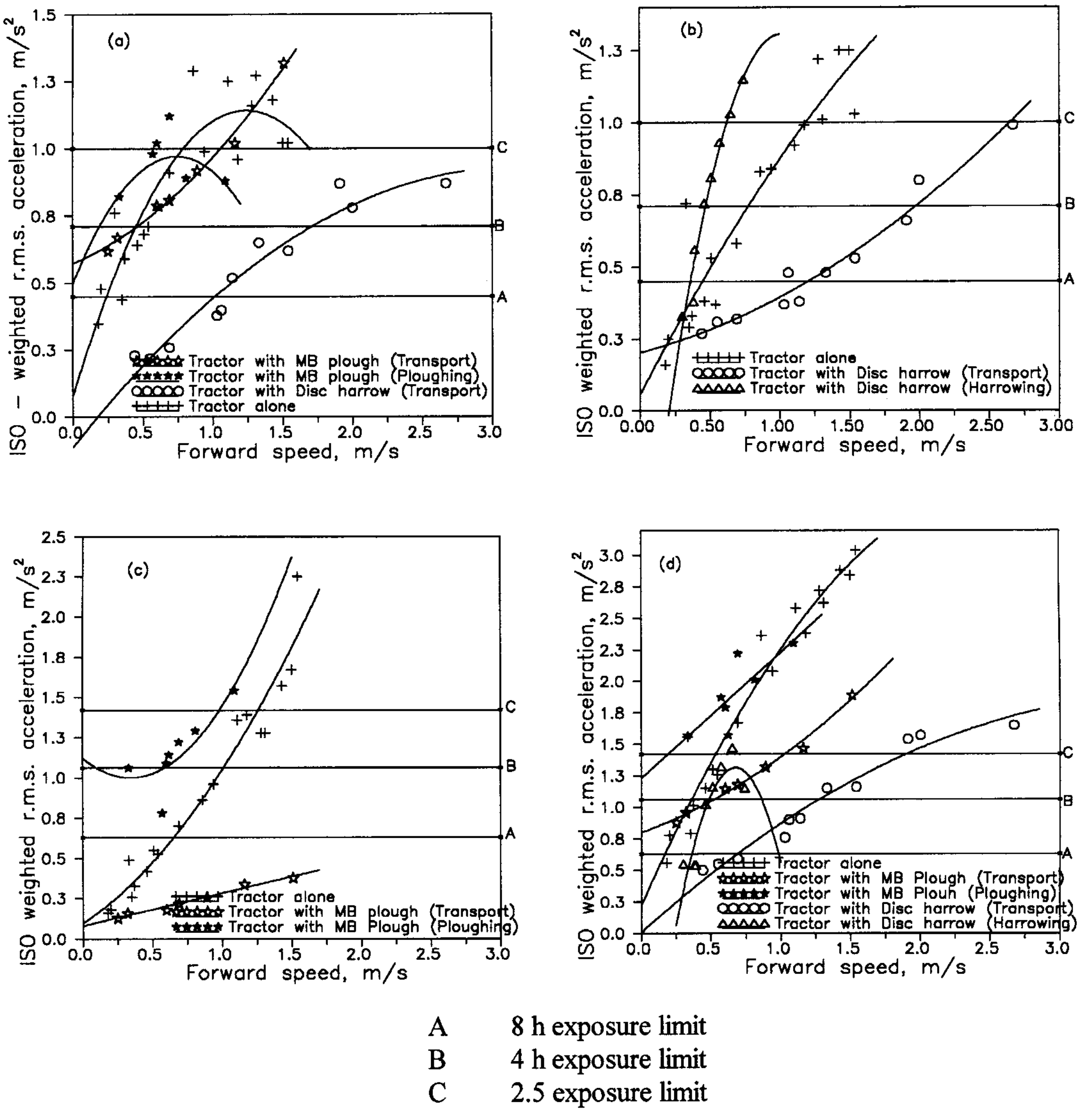

Fig. 2. Variation of acceleration level with forward speed of tractor-implement system: (a) Longitudinal acceleration level (a_x). (b) Lateral acceleration level (a_y). (c) Vertical acceleration level (a_z). (d) Sum acceleration level (SUM).

respectively (Fig. 1(d)). As per the British Standard (BS 6841, 1987), the likely human reactions to overall weighted r.m.s. accelerations are uncomfortable to very uncomfortable on the tar-macadam road and fairly uncomfortable to extremely uncomfortable on the farm road and untilled field.

5. Ride vibrations on tractor-implement system

The weighted r.m.s. acceleration levels in longitudinal axis (a_x) during harrowing operation, in lateral axis (a_y) during transport mode and ploughing operation and in vertical axis (a_z) during transport mode and harrowing operation were insignificant (less than 0.01 m/s^2) and therefore not recorded here. Fig. 2 shows that the ride vibration levels in all the axes were reduced by mounting either the MB plough or disc harrow except with MB plough in longitudinal axis (a_x). This may be due to the damping of tractor pitch and bounce by the vertical force on the implements. The damping effect was more prominent at higher forward speeds of the tractor.

The ride vibration levels in longitudinal axis were slightly damped for tractor with MB plough and significantly (40–70%) damped for tractor with disc harrow during transport mode, as compared to tractor alone on untilled field. Because the implement damped tractor pitch motion, and since the driver was not seated at the centre of pitch, his motion in the longitudinal axis was affected. On the untilled field, no conclusive difference in longitudinal vibration levels was found during transport mode of tractor alone and tractor with MB plough during ploughing operation. The longitudinal vibration levels during harrowing operation were insignificant (Fig. 2(a)). This may be due to the reason that the disc harrow drags behind the tractor.

The ride vibration levels in the lateral axis were increased sharply during harrowing operation. The speed of harrowing operation was restricted due to big clods of soil and wheel slippage. The ride vibration levels in the lateral axis were insignificant during ploughing operations (Fig. 2(b)). This may be because the MB plough does not have scope for lateral displacement because of support from soil pressure on the share and mould board and the support from the furrow wall.

The vertical ride vibration levels during ploughing operations were the highest. The vertical ride vibration levels were reduced by 65 to 80% and were within the 8 h exposure limit during transport mode for tractor with MB plough as compared to tractor alone. This may be due to the damping effect of the plough because the plough was wholly supported on the pneumatic tyres of the tractor through a three-point linkage system. The ride vibration levels decreased initially up to a forward speed of 0.57 m/s and then increased sharply with forward speed during ploughing operations (Fig. 2(c)), it may be due to variations in hardness of the soil and the resulting reaction force on the share point. The MB plough is integrally attached to the tractor through three-point linkage, and variation in horizontal force at share point leads to vibration in the vertical axis with the front wheels acting as pivot points. The vertical vibration levels during harrowing operations were insignificant, harrowing is a secondary tillage operation and vertical vibration arising from clod crushing may be damped by the weight of the disc harrow. The 2.5 h exposure limit is exceeded at a forward speed of 0.65 m/s during harrowing operation and at 1.09 m/s during ploughing operation in lateral and vertical axes, respectively.

The SUM acceleration levels during ploughing were higher than those during transport mode for tractor with MB plough. They got damped during harrowing operation but were higher than those for tractor with harrow in transport mode. The SUM acceleration levels exceeded the 2.5 h exposure limit at forward speeds of 1.16, 1.91 and 0.65 m/s during transport mode for the tractor with MB plough, transport mode for tractor with disc harrow and during harrowing operation, respectively (Fig. 2(d)). The damping effect was more pronounced in the case of the disc harrow as compared to MB plough at higher forward speeds. The overall weighted r.m.s. acceleration levels are uncomfortable to very uncomfortable for tractor with MB plough and fairly uncomfortable to uncomfortable for tractor with disc harrow at all forward speeds of travel during transport mode and field operations (BS 6841, 1987).

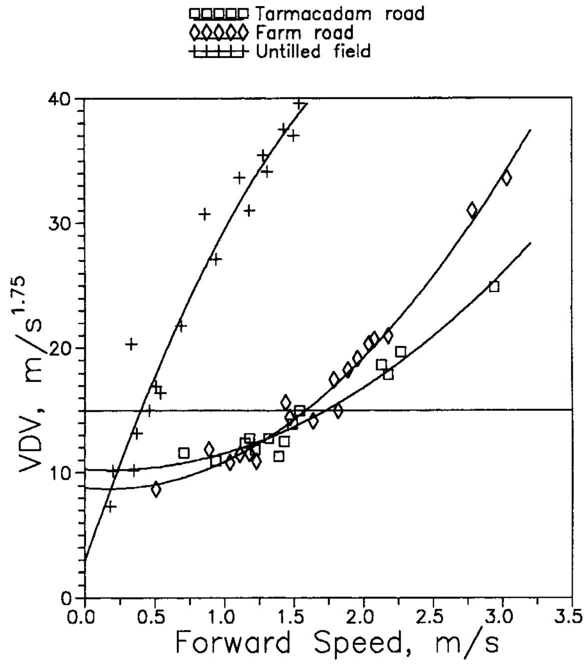

Fig. 3. Variation of vibration dose value with forward speed for 8 h exposure time during transport mode of the tractor.

6. Ride vibration evaluation by VDV

Figs. 3 and 4 show the variation of vibration dose values for 8 h exposure time with forward speed during transport mode of the tractor alone under different track conditions and during transport mode and field operations on the tractor-implement system under different operating conditions. The maximum recommended limit of VDV (BS 6841,1987) of 15 m/s$^{1.75}$ from the health point of view is superimposed on these figures.

The vibration dose value (VDV) for 8 h duration exceeded the recommended limit of 15 m/s$^{1.75}$ at forward speeds of 1.64, 1.79 and 0.51 m/s on tar-macadam road, farm road and untilled field, respectively. It exceeded the recommended limit at forward speeds of 0.69, 1.54 and 0.51 m/s for tractor with MB plough during transport mode, tractor with disc harrow during transport mode and harrowing operation, respectively. It exceeded the recommended limit at all tested forward speeds during ploughing operation.

7. Conclusions

The results show that the acceleration levels varied widely and were greatly dependent on variables such as forward speed, terrain conditions and mode of operation. The acceleration levels increased as forward speed of travel increased under most of the operating conditions. The ride vibration levels exceeded the ISO 4 and 8 h

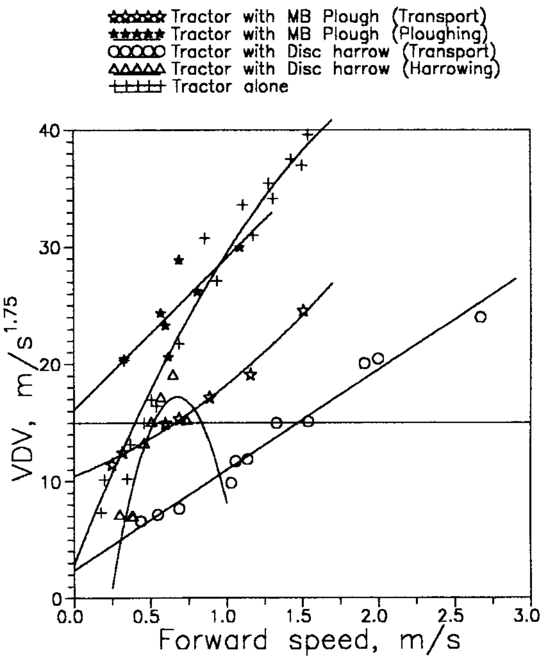

Fig. 4. Variation of vibration dose value with forward speed for 8 h exposure time of tractor-implement system.

exposure limits under most of the track and operating conditions. It is concluded that the exposure time for the tractor operator should not exceed 2.5 h during ploughing and harrowing operations. As per BS 6841 (1987), the overall weighted r.m.s. acceleration levels are uncomfortable to very uncomfortable during ploughing operation and fairly uncomfortable to uncomfortable during harrowing operation. Increasing the exposure time may cause severe discomfort, pain and injury.

This study helped in understanding the effect of farm implements on tractor ride vibration and in deciding appropriate exposure times for tractor operators for different field operations. The results indicated the value of research work aimed at reducing vibration levels in the size of tractor studied.

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