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Whole-body Vibrations, Evaluation of Emissions and Exposure Levels Arising from a Medium HP Farm Tractor

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Abstract: The present study was devoted to measure tractor floor and seat vibrations and to obtain average daily vibration exposure value (A8) and vibration dose value (VDV) experienced by tractor drivers. Both measures are dependent on measured vibration values. The A8 also requires an exposure time. The vibration dose value (VDV) provides an alternative measure of vibration exposure. The VDV is regarded as a measure that gives a better indication of the risks from vibrations that include shocks. The experiments were carried out for 3 drivers (weighting 600, 760 and 860 N) with Massey Ferguson 399 (82 kW). Performing mold board plowing (MB), chisel plowing (CH) and disk harrowing (DH) at equal forward speed of 4.5 km/h. Weighted RMS acceleration values were measured for axis perpendicular to driver seat based on international standards. Results show that in general WRMS acceleration values measured on driver seat for MB is significantly more than those for CH operation. Disk harrowing (DH) resulted in lower acceleration as compared to CH. Other findings show that driver seat markedly reduced vibration up to %8.For light weight tractor driver (600 N) tilling with MB resulted in the highest VDV level (15.37 $m/s^{1.75}$) which is more than harmful threshold (15 $m/s^{1.75}$), on the other hand CH by heavy weight driver (860 N) resulted in the least VDV (5.96 $m/s^{1.75}$). Similarly MB operated by light weight driver resulted in the highest A8 value (2.50 m/s^2) where CH by heavy driver has resulted in the least A8 value (1.01 m/s^2). However it should be noted that unfortunately drivers have been exposed to a level of whole body vibration well above recommended exposure level (1.15 m/ s^2) as stated by Directive 2002/44/EC.

Key words: Whole body vibration, medium HP farm tractor, vibration dose value (VDV), root mean square acceleration (RMS), daily exposure vibration (A8)

INTRODUCTION

Vibration exposure of agricultural workers is one of the most important topics concerning safety and comfort. The problem can be exacerbated by the increase in mechanization level of many activities recognized in the last decades. This is particularly true for tractor drivers, whose exposure can be time prolonged. Exposure takes place mainly through the seat and is related to several factors, among which agricultural activity, forward speed, ground profile, engine speed, seat features, can be cited (Butkta et al., 1998; Cutini and Bisaglia, 2007; Giunchi et al., 2008).

Several researches have been carried out to measure the levels of whole body vibration to which tractor drivers are exposed during farm activities (Scarlett et al., 2007; Pessina and Bonalume, 2009). These Authors report high levels of exposure during transfers and when old tractors are used, whose seats are often deteriorated or without an efficient suspension system.

Whole body vibrations transmitted to the tractor driver was measured during pesticide application in a citrus orchard when using a four wheeled isodiametric tractor and a conventional air assisted sprayer. The vibration exposure was computed for each working phase (transfer, spraying, turnings, transients, etc.). The main results showed that, with reference to the whole working cycle, the weighted root mean square (RMS) values of acceleration, were always slightly higher than the daily exposure action value fixed by the 2002/44/EC directive. Among different working phases, the highest values of acceleration occurred during transfers from and by the farm centre, where the tank of the sprayer was filled, due the higher forward speed. (Cerruto E et al., 2010).

A study was conducted to quantify whole-body vibration (WBV) emission and estimated exposure levels of modern, state-of-the-art agricultural tractors, operated in controlled conditions and whilst performing identical tasks during 'on-farm' use. Tractor WBV emission levels were found to be very dependent upon the nature of field operation performed, but largely independent of vehicle suspension system capability (due to the dominance of horizontal vibration). However, this trend was reversed during on-road transport. Few examples of tractor field operations approached or exceeded the Exposure Limit Value (ELV) during 8 hours operation, but this figure increased during longer 'working days. However virtually all 'on-farm' vehicles exceeded the Exposure Action Value (EAV) during an 8-hour day. (Scarlett et al., 2007)

A research was carried out to study vibration levels experienced by tractor operators under varying conditions of vibration while driving a tractor with and without farm equipment on different fields. Test runs were conducted in wet and dry fields to determine the levels of vibration generated at different engine speeds. On the basis of this study three levels of vibration were selected. Five subjects, all males, with no experience in the field of tractor driving participated in the study. The results showed that the main effects of farm equipment and the vibration level were statistically significant but the effect of field type was found to be non-significant. (Muzamil et al., 2004)

Longer exposure duration while performing plowing and harrowing operations may also cause severe discomfort, pain and injury. (Mehta et al., 2000). Increased risks for low back pain (LBP) disorders were reported among tractor drivers due to continuous exposure to whole body vibration (WBV). (Bovenzi, 1996). Similar results were obtained while quantifying tractor-driving time among Swedish farmers. (Toren et al., 2002)

Taghizadeh Alisaraei (2005) investigated vibration of tractor seat and its effects on driver in 5 levels of engine speed in vertical direction on tarmac road. Results of experiments indicated which tractor seat vibration frequency is twice the motor's rpm. and seat vibration frequency increased with increase in motor rpm. The study showed that vibration dose value (VDV) was in direct relationship with engine speed. Comparison of results with international standards indicated that for safety reasons time of exposure to vibration for high rpm levels should be decreased.

Maleki et al (2008) examined vibrations that the tractor operators of different weights were exposed when driving three commonly used tractors in Iran at different forward speeds. Acceleration data of tractor body and its driver, for the case of driver health and comfort were analyzed and evaluated. Results revealed that levels of forward speed did not have any significant effect on vibrations introduced to driver's body, however, the average of acceleration vectors of different tractors and their drivers bodies revealed a significant influence. Moreover, with increasing a driver's weight, the average of acceleration vectors on driver body was decreased. Also a comparison of acceleration vectors for different tractor operators, when compared with international standards, showed that the comfort level for these tractors was extremely low.

Vehicle vibration exposure has been linked to chronic back pain and low back symptoms among agricultural tractor drivers. A Study was conducted by the National Institute for Occupational Safety and Health (NIOSH) to assess driver whole body vibration (WBV) exposures and recommend interventions to reduce the risk of back related injuries, particularly relative to vehicle jarring/jolting (the transient mechanical shock components of WBV). Data were collected during mowing, raking, baling, chiseling. Whole Body Vibration measured at the operator/seat interface exceeded that of action level. The roughest rides and highest vector sum accelerations occurred with small utility tractor mowers and a skid steer loader. Major findings from health and work history data showed 96% of participants reported having to bend or twist their necks, although 24% reported neck symptoms. Sixty four percent of participating operators reported experiencing back symptoms (Mayton, 2008).

Measurements of vibrations were conducted on tractors of different sizes under varying terrain conditions. The comparisons revealed that measured vibrations exceed the 8 h exposure limit in one-third-octave frequency band ISO 2631-1 (1985) on both farm and non-farm terrains. In the overall ISO-weighted rms acceleration ISO 2631-1 (1997) in all farm and non-farm terrains working time of 3 h exceeded the upper limit of health guidance caution zone. (Kumar et al., 2001)

Soleki (2007) in a study conducted to assess the preliminary recognition of whole body mechanical vibration risk among several farmers in the rural work environment. This study covered 15 farms using cultivated land of the size of over 10 ha, carrying out mixed production (plant-animal), equipped with agricultural tractors, and a basic set of tractor-mounted agricultural machinery, with a partial contribution of self-propelled agricultural machines. Analysis of the peak, maximum and minimum vibration accelerations confirms that in the agricultural occupational environment there occurs a considerable variation of the vibration values registered. Analysis of the registered equivalent values of vibration acceleration (frequency corrected) from the hygienic aspect showed that vibration occurring on the seats may create risk for farmers' health. Analysis of the spatial distribution of the measured, frequency corrected vibration accelerations indicates that considerably the highest acceleration values occur in the vertical plane.

Literature data clearly confirm an unfavorable effect of the whole body vibration present in agricultural vehicles on discomfort and the occurrence of back pain in the operators, especially in the low back region as well as degenerative changes in the spine. (Soleki, 2007).

There are about 1470 tractor units Massey Ferguson 399 (81 kW) in Fars state, Iran. Considering extensive agricultural activities in Fars state, south of Iran and large number of farm tractors, this research was devoted to investigate vibration characteristics of MF-399 tractors common in the local agriculture and hazardous effects of these tractors on drivers' safety. Therefore the present study was devoted to measure tractor floor and seat vibrations and also obtains average daily vibration exposure value (A8) and vibration dose value (VDV) experienced by tractor drivers.

MATERIALS and METHOD

In this study some vibration characteristics of Massey Ferguson 399 tractors were studied (Table 1).

Tables 1 and 2 gives data pertaining to tractor used and drivers participated in the study.

The experiments were carried out for 3 drivers (weighting 600, 770 and 860 N) with a MF-399 tractor Performing moldboard plowing, chisel plowing and disk harrowing at 2200 rpm and gear 4. The accelerometer was accommodated on cabin floor and also on tractor driver seat to record vibration characteristics of each position. Field tests were conducted as a factorial experiment arranged in a complete randomized block design in three replications. Root mean square acceleration values were measured for axis perpendicular to driver seat based on international standards (ISO 2631-1). Raw data were used to calculate VDV and A8 values.

Table 1. Characteristics of tractor used in the study

Characteristics	MF 399
Number of cylinders	6
Maximum power	(at 2200 rpm) 110HP-81kW
Steering type:	hydromechanics type with adjustable front axle
Total weight	4011 kg
Tire pressure	front: 30 psi, rear: 20 psi

Table 2. Characteristics of the subjects participated in the study.

Characteristics	Driver 1	Driver 2	Driver 3
Age (yr)	27	48	21
Height (cm)	161	162	165
Weight (kg)	60	77	86

Table 3. Characteristics of the implements used in the study

Implements	Mounting	
Mold board plow	Semi mounted	4 bottom
Chisel plow	Mounted	11 shank, total width: 246 cm
Disk harrow (offset)	Semi mounted	24 disk, Disk diameter: 90 cm

Before conducting field experiment tractor tires' pressure was adjusted to the recommended level and tractor seat was adjusted for the particular driver (driver weight) as advised by the manufacturer, by a (50-120 kg) adjustable, knob spring tension control treatment.

Acceleration, A8 and VDV experienced by three tractor drivers during tilling operations were measured. Furthermore acceleration of the tractor chassis under seat (cabin floor) mounting was also monitored by a piezoelectric transducer accelerometer to study the damping effects of the driver seat.

The a_{wrms} values for each test was used to calculate two important indices of vibration; Daily exposure value (known as A8) and Vibration dose value (VDV). Considering the importance of these two measures, the following section is devoted to introduce each briefly (ISO 2631-1:1997).

RESULTS and DISCUSSION

Results of the study showed that the vibrations generated during field tests have strong statistically significant effects on A8 and VDV values.

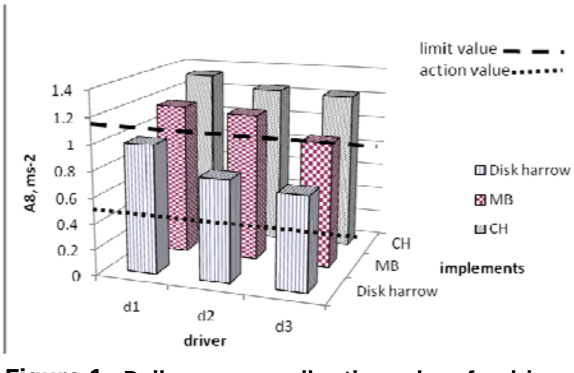

Figure 1. Daily exposure vibration values for drivers participated in the tests as compared to limit and action values

Comparison of A8 values for various drivers and field operations showed that with no regard to type of implement, light weight driver (60 kg) was subjected to more vibration for operating time (8 h) as compared to other drivers. In other words the light weight driver has been subjected to harmful levels of vibration since his acceleration exceeds both action and limit values criterion (0.5 and 1.15 ms^{-2}, respectively) where other drivers were experiencing high and harmful levels of vibration (Fig. 1).

This figure also shows that disk harrowing resulted in the least vibration as compared to other two operations but chisel plowing resulted in the highest vibration, therefore it may be concluded that the driver seat spring assembly must be recalibrated to further damp seat vibration especially for light weight drivers. Highest A(8) value occurred for driver with weight of 60 kg while chisel plowing whereas the lowest occurred for driver with weight of 86 kg for disk harrowing.

Comparing means of daily exposure value showed that driver with least weight experienced the highest daily exposure vibration value. vibration for all drivers while disk harrowing with three tractor setting were more than of action value level of 0.5 ms^{-2} so drivers existed in alarm threshold and except disk harrowing in gear 6 at 2200 rpm for driver with weight of 60 kg other operations existed less than of limit value level of 1.15 ms^{-2} which need to necessary accomplishment for this driver exposure to high limit value level of vibration for reduction of vibration to transmitted to driver seat. For example modify the driver seat or pressure tire of tractor wheels are change and their less. Also notice to seat spring condition could be useful. Moreover without notice to weight of driver value of A(8) was differenced for three tractor setting which with also the value of A(8) increased. Most of A(8) value was occur for driver with weight of 60 kg while gear 6 at 2200 rpm and at least was occur for driver with weight of 86 kg while at gear 4 at 2200 rpm (Table 4).

Comparison of mean VDV for all drivers while performing three field operations indicate that is significantly more distant to limit level of 15 $ms^{-1.75}$ (British Standards Institution, 1987). More over Comparison of mean VDV indicate that with no regards to various weights of drivers value of VDV was differenced significant for each three implements, chisel plowing has the maximum value and disk harrowing has the minimum value.

Table 4. Comparison of A8 values for various drivers and tractor settings (Z direction)

Drivers[1]	Tractor setting[2] TS1	TS2	TS3	Mean
Driver1	0.99[a$]	1.11[a]	1.28[a]	1.13[A†]
Driver2	0.78[b]	1.0[b]	1.12[b]	0.97[B]
Driver3	0.72[b]	0.9[c]	1.1[b]	0.91[B]
Mean	0.83[A‡]	1.0[B]	1.17[C]	

1: Drivers weight: 60, 77, 86 kg, respectively,
2: Ts; tractor settings: TS1, TS1, TS1 gears 4, 5, 6 in 2200 rpm respectively,
3: $For each parameter, means within each column followed by the by the same letters are not significantly different at P< 0.01,
4: †For each parameter, means within each column followed by the by the same capital letters are not significantly different at P< 0.05,
5: ‡For each parameter, means within each row followed by the same capital letters are not significantly different at P< 0.01.

Table 5. Comparison of VDV values for various drivers and tractor settings (z direction)

Drivers[1]	Tractor setting[2] TS1	TS1	TS1	Mean
Driver1	5.82[ab*]	6.72[a]	6.67[a]	6.73[A**]
Driver2	4.64[c]	6.03[b]	6.78[b]	5.81[B]
Driver3	4.39[c]	5.51[c]	6.65[b]	5.51[B]
Mean	4.95[A***]	6.08[B]	7.02[C]	

1: Drivers weight: 60, 77, 86 kg, respectively,
2: Ts; tractor settings: TS1, TS1, TS1 gears 4,5,6 in 2200 rpm respectively,
3: $For each parameter, means within each column followed by the by the same letters are not significantly different at P< 0.01,
4: †For each parameter, means within each column followed by the by the same capital letters are not significantly different at P< 0.05,
5: ‡For each parameter, means within each row followed by the same capital letters are not significantly different at P< 0.01.

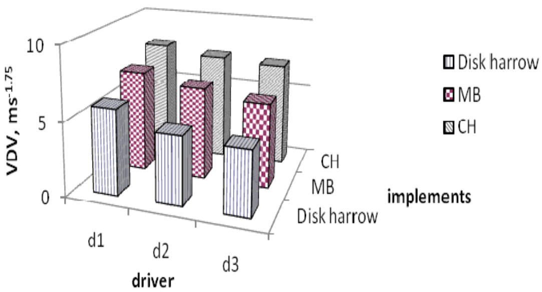

Figure 2. Vibration dose value values for drivers participated in the tests

As expected the mean VDV values for drivers is less for light weight driver with 60 kg weight than heavy weight driver with 86 kg weight may not be different. Results showed that most of VDV value occurred for driver with weight of 60 kg while chisel plowing and minimum was occurred for driver with weight of 86 kg while disk harrowing (Fig. 2).

Comparing means of daily exposure value showed that driver with least weight experienced the highest daily exposure vibration value. vibration for all drivers while disk harrowing with three tractor setting were statistically significant more than of action value level of 0.5 ms^{-2} so drivers existed in alarm threshold and except disk harrowing in gear 6 at 2200 rpm for driver with weight of 60 kg other operations existed less than of limit value level of 1.15 ms^{-2} which need to necessary accomplishment for this driver exposure to high limit value level of vibration for reduction of vibration to transmitted to driver seat. For example modify the driver seat or pressure tire of tractor wheels are change and their less. Also notice to seat spring condition could be useful. Moreover without notice to weight of driver value of A(8) was statistically significant for three tractor setting which with also the value of A(8) increased. Most of A(8) value was occur for driver with weight of 60 kg while gear 6 at 2200 rpm and at least was occur for driver with weight of 86 kg while at gear 4 at 2200 rpm (Table 5).

CONCLUSIONS

- Comparing means of VDV values for drivers with no regard to various tractors settings showed that Irrespective to driver weight value of VDV was statistically significant for three tractor settings, as the tractor weight increased, the VDV decreased.
- Value of VDV was highest for gear 6 at 2200 rpm and least for gear 4 at 2200 rpm.
- The highest VDV value was experienced while disk harrowing for driver with weight of 60 kg and lowest VDV was felt by driver with weight of 86 kg.
- All the drivers while disk harrowing felt VDV values significantly under 15 $ms^{-1.75,}$ it imparts least damage to the driver health
- Results showed that with no regard to type of implement, light weight driver (60 kg) was subjected to more vibration for operating time (8 h) as compared to other drivers This figure also shows that disk harrowing resulted in the least vibration as compared to other two operations but chisel plowing resulted in the highest vibration,. In other words the light weight driver has been subjected to harmful levels of vibration since his acceleration exceeds both action and limit values
- Disk harrowing resulted in the least vibration as compared to other two operations but chisel plowing resulted in the highest vibration,
- It may be concluded that the driver seat spring assembly must be recalibrated to further damp seat vibration especially for light weight drivers.

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