Health Hazard Assessment of Tractor Driver Whole-body Vibration Utilizing the ISO 2631 Standard

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Summary

In order to quantify tractor driver Whole-Body Vibration (WBV) induced by some of the agricultural operations, the ISO 2631 standard was utilized. Detailed methodology of the calculation of the WBV evaluating indices using the time-domain acceleration data analysis was presented. According to the results of the study, typical weighted root mean square (WRMS) value of the Z-axis vibration was more than the WRMS value of the X and Y axes vibrations. Furthermore all of the severity categories (SV) obtained from driving the tractor on asphalt road, plowing and power tilling based on the equivalent daily stress index (S_{ed}), were graded in the class of 3 or 4; which means that the health hazard associated with these operations is marginal. Finally among the examined machines; the locally built, tractor front mounted, hydraulic power aided loader caused vibrations that were slightly higher than the exposure limit value (ELV), with regard to the parameter of WRMS over an eight hour period (A(8)).

Key words

agricultural tractor; digital filter; frequency weighting; ISO 2631; risk assessment; whole-body vibration

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Introduction

All on-road and off-road vehicles are exposed to vibrations caused by unevenness of road or soil surface and moving elements within the vehicle or its attached implements (Hostens and Ramon, 2003; Nguyen and Inaba, 2011). With regard to this fact, it is widely recognized that tractor drivers are exposed to fairly high levels of whole-body vibration (WBV) during typical farm operations (Hostens et al., 2004; Scarlett et al., 2007). The vibration of agricultural tractors is undesirable, not only because of the reduced comfort and possible health degradation of the driver, but also because of the increased dynamic stresses that may lead to fatigue and failure of the tractor components (Loutridis et al., 2011). Researchers conclude that the chronic effects of increased ride vibration levels on the tractor driver are vascular, neurological and musculoskeletal disorders (Goglia et al., 2006). As an example Hostens and Ramon (2003) stated, "Agricultural machinery workers report performance problems usually associated with back pain and sitting discomfort. Low-frequency (2–20 Hz) cyclic motions like those caused by a vehicle's tires hitting the road can put the body into resonance." High levels of low-frequency vibration are transmitted to the seat of agricultural machinery driver and affect the driver's health. Particularly, severe physical damage may happen by long term exposure of the backbone in this frequency range. Just one hour of seated vibration exposure can cause muscle fatigue, weaken the soft tissues and make a worker more susceptible to back injury. Statistical analyses of health problems associated with different jobs showed that occupations that involve driving transportation vehicles are present more frequently in patients with low back pain than in a reference group without back pain; specifically, the prevalence of reported back pain is approximately 10% higher in tractor operators than in workers without vibration exposure (Hostens and Ramon, 2003). On the other hand, accelerometers may be used to measure human exposure to vibration; and weighting filters are required to correlate the physical vibration measurements to the human's response to vibration. ISO 2631 standard describes suitable weighting filters, but does not explain how to implement them for digitally recorded acceleration data. The aim of the digital data filtering is the modification of the frequency and phase response of a system by applying a series of multiplications and additions to the time domain data. Digital filtering can be done using one of these methods: Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) (Rimell and Mansfield, 2007). FIR method formula is given in equation 1:

$$y[n] = \sum_{k=0}^{M} b_k \cdot x[n-k] \tag{1}$$

Where b_k is the k^{th} filter coefficient and x[n-1] is the previous data sample (previous input value). However, an IIR filter uses previous input values as well as previous output values to calculate the current output sample value, which may be given by equation 2:

$$y[n] = \frac{1}{a_0}\left(\sum_{j=0}^{M} b_j \cdot x[n-j] - \sum_{k=1}^{M} a_k \cdot y[n-k]\right) \tag{2}$$

The advantage of IIR relative to FIR filter is that because IIR filtering is recursive, it requires less coefficients than the equivalent FIR filter; however, a poor design of an IIR filter may result in an unstable filter. Fortunately Rimell and Mansfield (2007) designed digital IIR filters for frequency weighting required for health hazard assessment of workers exposed to machinery vibration; furthermore Alem (2005) summarized some of the formulas used for evaluation of the health risk associated with a vibration exposed driver. He examined root mean square (RMS), vibration dose value (VDV), and risk factor (R) indices for this purpose. In this study to address the health risks associated with tractor driver exposed to WBV, an investigation was carried out to:

- Measure time history of tractor driver WBV utilizing accelerometer,
- Convert measured vibration to appropriate human's response vibration using frequency weighting filters with the aid of the method described by Rimell and Mansfield (2007),
- Apply ISO 2631-1, and ISO 2631-5 standards to assess health hazards of frequency weighted vibration.

Methods

In order to measure vibration a three axes accelerometer was used. Acceleration measuring apparatus utilized in this study was designed and built during executing a research project conducted in the IAU-Khorasgan branch (Ahmadi, 2012). A photograph of its components is shown in Figure 1.

Frequency response of the accelerometer sensor was from 1 Hz to 500 Hz. A sampling rate of 100 Hz was used and typically 180s of data were acquired in each single experiment. The accelerometer sensor was attached to the cushion of tractor driver's seat using duct tape to prevent it from slipping away during operations. The sensors measured accelerations in X, Y and Z directions simultaneously. ISO 2631-1 standard was used to define the reference axis system, with X, Y and Z axes corresponding to longitudinal, transverse and vertical vibration respectively.

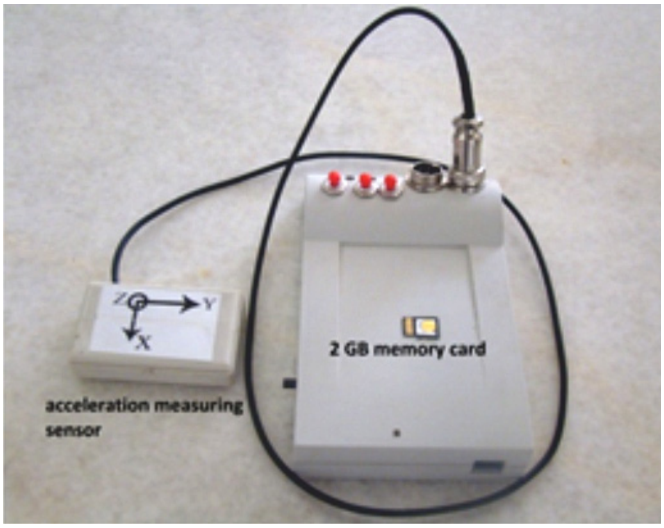

Figure 1. Tractor seat vibration measuring apparatus

Table 1. Technical specifications of the examined tractor (MF 285)

Technical specifications	Measurement unit	
Engine type		4 cylinder, diesel
Rated power	kW/HP	56/75
Rated engine speed	rpm	2000
Speed regulator		Mechanical governor
Transmission type		Synchromesh gearbox
Front power lift		Locally built loader
Driver's seat		Compact mechanical suspension
Rear tire		6 layer 18.4×15-30
Front tire		6 and 8 layer 7.5-16
Length-width-height	mm	4010×2060×1680
Wheel base	mm	2290
Total weight	kg	2812

The tractor used to conduct the experiments was an MF 285, two wheel drive tractor (see specifications in Table1).

There was not any conventional suspension system between chassis and cab of the examined tractor, however two blocks of compacted rubber were installed on each side of the tractor between chassis and tractor cab as silent blocks, and the driver's seat was equipped with a mechanical suspension.

The time-domain data of vibration induced by driving the tractor on asphalt road, plowing, power tilling with different forward velocities and hydraulic power aided loading were stored into a 2 G-byte nonvolatile memory that can be transferred to a PC for further analysis at a later date.

The influence of vibration on a human depends on frequency; therefore it is necessary that accelerometers are able to provide reliable time history vibrations at the most important frequency. ISO 8041 determined that the band limiting filter of WBV should occur at 0.4 Hz and 100 Hz, and therefore measurement apparatus should be selected to have a nominally linear response at least within this frequency range. It may be concluded that the measured data should be "weighted" to give greater emphasis to frequencies where humans are most sensitive.

Furthermore, in order to have comparable data obtained from different equipments, it is essential to use standard methods for frequency weighting. Two standards are in common use for frequency weighting of WBV measurements: ISO 2631-1 and BS 6841. The methodology used in this study to design frequency weighting filters was according to the methodology described by Rimell and Mansfield (2007). Stages of this procedure are as follows:

Definition of suitable frequency weighting filters

Frequency weighting filters used in ISO 2631-1 and BS 6841 for seat vibration are W_b, W_d and W_k, where W_b and W_k are suitable for vertical vibration filtering in BS 6841 and ISO 2631 standard respectively and W_d is suitable for fore-aft and lateral vibration filtering in both of the standards. Each of these filters consists of a number of sub-filters, which are then cascaded in different combination to produce a suitable filter. In ISO 2631 and BS 6841 standards, analogue transfer functions were utilized to represent each of the sub-filters; these transfer functions were labeled as "high pass", "low pass", "acceleration-velocity transition" and "upward step", which can be expressed in s-domain as follows (In the following equations ω_i is angular frequency (*rad/s*), f_i is frequency (*rev/s or Hertz* (*Hz*)) and Q_i is constant (*dimensionless*):

$$\text{High pass sub-filter: } H_h(s) = \frac{s^2}{s^2 + \frac{\omega_1}{Q_1}s + \omega_1^2} \tag{3}$$

$$\text{Low pass sub-filter: } H_l(s) = \frac{{\omega_2}^2}{s^2 + \frac{\omega_2}{Q_2}s + \omega_2^2} \tag{4}$$

Acceleration-velocity transition sub-filter:

$$H_t(s) = \frac{\frac{\omega^2{}_4}{\omega_3}s + \omega_4^2}{s^2 + \frac{\omega_4}{Q_4}s + \omega_4^2} \tag{5}$$

$$\text{Upward step sub-filter: } H_s(s) = \frac{s^2 + \frac{\omega^2{}_5}{Q_5}s + \omega_5^2}{s^2 + \frac{\omega_6}{Q_6}s + \omega_6^2} \tag{6}$$

Combination of equations 3 to 6 that comprises each filter is defined in Table 2 and the numeric values to be used were shown in Table 3.

In this study only the ISO 2631 standard was used for frequency weighting of WBV time histories; moreover, tractor vibrations were recorded utilizing a digital data logger that stores data in the time-domain; therefore it is ideal to perform data filtering in the time-domain too; furthermore since IIR filter

Table 2. Arrangement of the sub-filters to produce each of the weighting filters

Filter	Combination of sub-filters
W_b	$1.15 \times H_h(s) \times H_l(s) \times H_t(s) \times H_s(s)$
W_d	$H_h(s) \times H_l(s) \times H_t(s)$
W_k	$H_h(s) \times H_l(s) \times H_t(s) \times H_s(s)$

Table 3. Numeric values to be used in equations 3 to 6 (ω=2πf)

Sub-filter name	Sub-filter parameters	Frequency weighting filter name		
		W_b	W_d	W_k
H_h	f_1(Hz)	0.4	0.4	0.4
	Q_1	0.70710678	0.70710678	0.70710678
H_l	f_2(Hz)	100	100	100
	Q_2	0.70710678	0.70710678	0.70710678
H_t	f_3(Hz)	16	2	12.5
	f_4(Hz)	16	2	12.5
	Q_4	0.55	0.63	0.63
H_s	f_5(Hz)	2.5	-	2.37
	Q_5	0.9	-	0.91
	F_6(Hz)	4	-	3.3
	Q_6	0.95	-	0.91

was utilized for digital data filtering, the coefficients of the filter must be calculated, which was performed using bilinear transform method.

Bilinear transform for calculation of the IIR filter coefficients

In the bilinear transform method of digital IIR filter design, s in analogue s-domain equation is replaced by $2\frac{(1-z^{-1})}{(1+z^{-1})}$. However there is a non-linearity between analogue and digital frequencies, which can be eliminated using pre-warping the frequencies used in the analogue s-domain equations. Pre-warping converts the normalized filter design frequency (ω_n) to the normalized warped frequency (ω'_n), using equation 7:

$$\omega'_n = 2\tan(\frac{\omega_n}{2}) \tag{7}$$

In equation 7, ω_n is defined as $2\pi\frac{\omega_c}{\omega_s}$, where ω_c is the center angular frequency (*rad/s*) and ω_s is the angular sampling frequency(*rad/s*). If s in analogue s-domain equations of 3 to 6 is replaced by $2\frac{(1-z^{-1})}{(1+z^{-1})}$, and simplified until it is in the form of $H(z)=\frac{b_2z^{-2}+b_1z^{-1}+b_0}{a_2z^{-2}+a_1z^{-1}+a_0}$, the filter coefficients (a_0 to a_2 and b_0 to b_2), which are all dimensionless coefficients, may be read directly, but it should be considered that the normalized warped frequency (ω'_n) must be substituted into its corresponding normalized frequency (ω_n). Finally the filtered acceleration can be calculated using this Matlab software command (MathWorks® Matlab version 7.12.0.635 (R2011a)): Filter (b,a,x), where "a" is the matrix of the coefficients of the denominator of the function H(z) (i.e. a=[a_0,a_1,a_2]), "b" is the matrix of the coefficients of the numerator of the function H(z) (i.e. b=[b_0,b_1,b_2]) and x is the matrix of the input acceleration data (Loutridis et al., 2011).

Now, the coefficients of all of the sub-filters are prepared as functions of the sampling frequency of the data acquisition system. In order to complete the full frequency weighting, the sub-filters must be cascaded according to the arrangement represented in Table 2, where the output from the previous sub-filter must be used as the input to the next one.

Calculation of the WBV evaluating indices

After obtaining the final frequency weighted data ($a_w(t)$), measured in *m/s*^{2} as a function of time, the following indices were used for evaluating the WBV induced by some of the operations performed in the field of agriculture:

Weighted Root Mean Square acceleration over an eight hour period (A(8), *m/s*^{2})

$$A(8)=WRMS\sqrt[2]{\frac{T}{3600\times 8}}$$

Where T is the duration of the measurement (*in seconds*) and WRMS is the Weighted Root Mean Square of acceleration data (*m/s*^{2}), which is calculated as:

$$WRMS=\sqrt[2]{\frac{1}{T}\int_0^T a_w^2(t)dt}\cdot$$

Vibration Dose Value over an eight hour period (VDV(8), *m/s*$^{1.75}$)

$VDV(8)=VDV\sqrt[2]{\frac{T}{3600\times 8}}$, where VDV is defined as follows:

$$VDV=\sqrt[4]{\frac{1}{T}\int_0^T a_w^4(t)dt}$$

Q7 and Q8 dimensionless screening ratios (defined in ISO 2631-1)

$Q7=\frac{MTVV}{WRMS}$ and $Q8=\frac{VDV}{WRMS\cdot\sqrt[4]{T}}$, where MTVV (*m/s*^{2}) is the Maximum Transient Vibration Value calculated as:

$$MTVV=\max\sqrt[2]{\frac{1}{\tau}\int_{t_0-\tau}^{t_0} a_w^2(t)dt}$$

MTVV is the running RMS method that takes into account occasional shocks by using a short integration time constant τ=1sec. If these screening ratios, i.e. Q7 and Q8, exceeded 1.5 and 1.75, respectively, use of additional evaluation methods (beyond the RMS method) are recommended.

Risk factor R (Dimensionless) (defined in ISO 2631-5)

$$R=\sqrt[6]{\sum_{i=1}^{n}(\frac{S_{ed}\cdot\sqrt[6]{days}}{S_{ui}-c})^6}$$

Where "days" is the number of days per year that the driver is exposed to vibration, n is the number of years of exposure, c is a constant equal to 0.25 *MPa* for driving posture, S_{ui} (*MPa*) is the ultimate strength of the lumbar-spine for a person of age (b+i) years, with b being the age at which the exposure starts, mathematically S_{ui} (*MPa*) may be calculated as a function of (b+i) (in years) as: $S_{ui}=6.75-0.066\times(b+i)$, and S_{ed} (*MPa*) is the equivalent daily stress defined as:

$S_{ed}=\sqrt[6]{\sum_{k=x,y,z}(m_kD_{kd})^6}$, where m_ks (*kg/km*^{2}) are constants for x, y and z directions (m_x=0.015, m_y=0.035 and m_z =0.032), and D_{kd} (*m/s*^{2}) is the average daily acceleration dose for each direction k, calculated as:

$D_{kd}=D_k\sqrt[6]{\frac{t_d}{t_m}}$, where, t_d (s) is the duration of an average workday, t_m (s) is the period of vibration sampling i.e. T (s) and D_k (*m/s*^{2}) is the acceleration dose defined as:

$D_k=\sqrt[6]{\sum_{i=1}^{m}A_{ik}^6}$, where A_{ik} is the ith peak of the acceleration (*m/s*^{2}) in the k-direction (k=x,y,z) and m is the number of peaks in the measured signal.

Table 4. Health hazard severity categories of WBV and repeated shock

WBV, ISO 2631-1		Repeated shocks, ISO 2631-5		Health Hazard Assessment, (HHA) AR 40-10
WBV Daily Exposure Limit (minutes)	Vibration Dose Value VDV(8) ($m/s^{1.75}$)	Equivalent Daily Stress, S_{ed} (MPa)	Risk Factor, R	Severity Category (SC)
<10	>21	>0.95	>1.4	1-Catastrophic
10-30	13-21	0.65-0.95	1.4-1.0	2-Critical
30-180	4-13	0.35-0.65	1.0-0.6	3-Marginal
>180	<4	<0.35	<0.6	4-Negligible

Calculations of the indices were performed using code writing environment of Matlab software (see appendix of the paper).

In order to compare vibration indices of different operations done by the agricultural tractors, the Severity Category (SC) used by Alem (2005), and the criterion of the European Physical Agents (Vibration) Directive:2002 (PA(V)D), were considered. The SC that is based on the convention used by U.S. Army Aero-medical Research Laboratory (USAARL) to assign health hazard severity of WBV and repeated shock is shown in Table 4.

Table 5. Boundaries of exposure action and limit values according to EU legislation (PA(V)D)

	WRMS (8) or A(8)	VDV(8)
EAV	0.5 m/s^2	9.1 $m/s^{1.75}$
ELV	1.15 m/s^2	21.0 $m/s^{1.75}$

Furthermore, EU legislation specified two daily vibration exposure levels: Exposure Action Value (EAV) and Exposure Limit Value (ELV), which are defined in terms of WRMS acceleration and VDV over an eight hour period as shown in Table 5:

Results

Typical time histories of acceleration data obtained along three Cartesian axes i.e. X, Y and Z were shown in Figure 2.

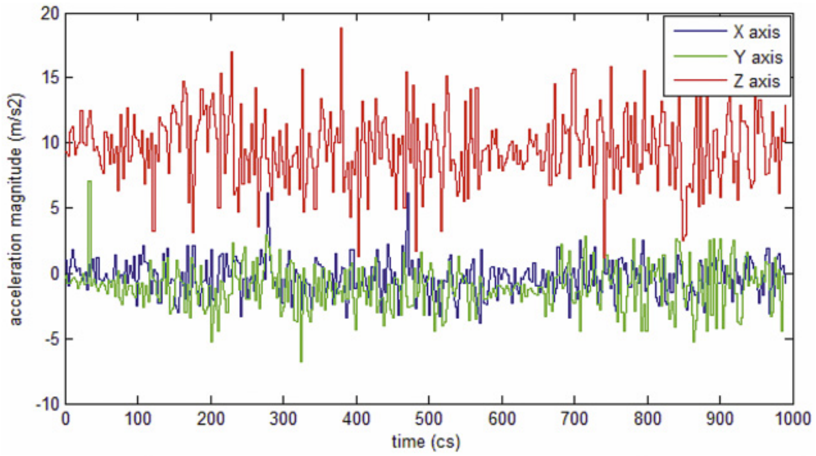

Figure 2. Acceleration data obtained along X, Y and Z axes against time

As can be seen from Figure 2, the vibration values along Z axis are more than the vibration values along X and Y axes.

Another result of this study is eleven ride pad acceleration signatures (from driving tractor on asphalt road, plowing, power tilling; each with three different forward velocities, and hydraulic power aided loading) which were obtained and processed using the methodology described in section Methods. Brief results of the calculations are given in Table 6 (The ground type and tractor speed are included in Table 6 to provide better perspective of the conditions of the experiments and to help explain unusual results):

The ISO 2631 standard uses the magnitude of A(8) or VDV(8) as suitable parameters to differ between EAV and ELV. With regard to this fact, Table 6 shows that the vibrations along Z axis in all of the examined machines except the tractor front mounted, hydraulic power aided loader were lower than the ELV. On the other hand, screening ratios of Q7 and Q8, which may be utilized to differ between vibration time histories with and without repeated shocks, show that according to USAARL criterion none of the machines caused repeated shocks, because in USAARL criterion the acceleration time histories with values of Q7 and Q8, which are higher than 1.5 and 1.75 respectively, are considered to have high shock content and should be processed using other methods. It is informative to note that Q7 and Q8 ratios are similar to the crest factor defined as the ratio of the maximum weighted acceleration value to the WRMS $(crest \quad factor = \frac{\max(a_w(t))}{WRMS})$, to classify signals as ones containing shocks. If crest factor of the weighted acceleration data was higher than nine then the VDV would have to be computed for evaluation of risk to health.

In addition to the vibration time history, the calculation of the Risk factor index (R) needs some extra information about the number of years that the tractor driver was exposed to vibration up to the vibration measurement instant, the age of tractor driver at which the exposure started and exposure duration per year, which means that this index should be calculated individually for an examined driver, therefore in this study, the equivalent daily stress (S_{ed}) was calculated and listed in Table 6. As can be seen, all of the examined cases had the severity category (SC) of 3 or

Table 6. Results of data analysis for acceleration time histories of the experiments

Ground type	Operation type	Velocity	Vibration axis	Basic Method			Screening ratios		VDV Method			Risk factor method	
				WRMS (m/s^2)	A(8)	SC	Q7	Q8	VDV(8) $(m/s^{1.75})$	SC		S_{ed} (MPa)	SC
Asphalt	Driving with high gears	1st gear 5 km/hr	x	1.18	0.09	-	0.85	0.50	1.66	-	4	0.31	4
			y	2.48	0.20	-	1.10	0.54	3.22	-	4		
			z	10.54	0.84	EAV	1.12	0.44	9.17	EAV	3		
		2nd gear 7 km/hr	x	1.20	0.10	-	0.84	0.55	1.57	-	4	0.33	4
			y	2.51	0.20	-	0.81	0.53	3.39	-	4		
			z	10.62	0.85	EAV	0.93	0.41	9.82	EAV	3		
		3rd gear 10 km/hr	x	1.36	0.11	-	0.81	0.53	1.83	-	4	0.35	3
			y	2.60	0.21	-	1.03	0.53	3.50	-	4		
			z	10.64	0.85	EAV	0.88	0.42	10.38	EAV	3		
Not tilled	Plowing with low gears	1st gear 1.5 km/hr	x	1.32	0.11	-	0.94	0.45	1.74	-	4	0.37	3
			y	2.13	0.17	-	0.51	0.44	2.75	-	4		
			z	10.02	0.80	EAV	1.09	0.32	10.69	EAV	3		
		2nd gear 3 km/hr	x	1.43	0.11	-	0.78	0.42	1.92	-	4	0.38	3
			y	2.58	0.21	-	1.37	0.39	3.22	-	4		
			z	10.43	0.83	EAV	0.96	0.33	11.06	EAV	3		
		3rd gear 4.5 km/hr	x	1.45	0.12	-	0.69	0.43	2.07	-	4	0.39	3
			y	2.89	0.23	-	1.31	0.41	3.86	-	4		
			z	10.58	0.85	EAV	0.82	0.36	11.19	EAV	3		
Tilled	Power tilling with low gears	1st gear 1.5 km/hr	x	1.30	0.10	-	1.45	0.52	1.79	-	4	0.31	4
			y	2.14	0.17	-	0.61	0.52	2.97	-	4		
			z	10.77	0.86	EAV	0.98	0.44	11.58	EAV	3		
		2nd gear 3 km/hr	x	1.41	0.11	-	0.74	0.60	2.08	-	4	0.35	3
			y	2.51	0.20	-	0.81	0.53	3.39	-	4		
			z	10.79	0.86	EAV	1.02	0.40	11.39	EAV	3		
		3rd gear 4.5 km/hr	x	1.44	0.12	-	0.80	0.49	1.88	-	4	0.4	3
			y	2.84	0.23	-	0.54	0.45	3.64	-	4		
			z	10.88	0.87	EAV	1.13	0.38	11.84	EAV	3		
Hard soil	Loading	locally made loader	x	2.15	0.17	-	1.50	0.53	1.28	-	4	0.45	3
			y	1.95	0.16	-	1.40	0.48	3.50	-	4		
			z	14.53	1.16	ELV	1.35	0.40	14.40	EAV	2		
		factory made loader	x	1.03	0.08	-	1.35	0.50	1.28	-	4	0.23	4
			y	0.93	0.07	-	1.08	0.51	1.19	-	4		
			z	7.57	0.61	EAV	1.08	0.41	7.85	EAV	3		

4, which means that the health hazard associated with these operations is negligible or marginal.

Discussion

The observed trend of acceleration data variations along X, Y and Z axes (Figure 2) is in agreement with previous work about the effects of electronic speed regulator on whole-body vibration measurements by Loutridis et al. (2011). They reported that the Z axis acceleration in all of the cases considered was higher than the acceleration obtained along X and Y axes.

Furthermore among the examined machines, the hydraulic power aided loader had an A(8) parameter that was higher than ELV, maybe because it was built locally and with low quality design, therefore during the tests of the loader repeated shocks were observed. However, by utilizing a factory made, tractor front mounted loader, the value of the A(8) parameter was reduced to an acceptable range of [EAV, ELV]. Similar trend was observed regarding the VDV(8) utilizing PA(V)D; however, a more detailed classification of operations according to this parameter was obtained using USAARL criterion, therefore USAARL criterion is more conservative than the PA(V)D method.

Another conclusion that can be inferred from the observed data is that increase of the tractor velocity leads to the slight increase of the evaluating parameters, maybe because of the fact that the tractor passing over the obstacles of the field with different forward velocities, affects the frequency of tractor vibrations, which consequently results higher magnitude of the evaluating parameters. This result is in agreement with previous work done by Scarlett et al. (2007) that was about quantifying WBV emission and estimated exposure levels found upon a range of modern agricultural tractors. They concluded that WBV emission levels were found to increase in proportion with forward speed, irrespective of the suspension system capability of the test vehicles.

Conclusion

In this study whole body vibration of an MF 285 tractor driver induced by the operation of some of the equipment typically found on agricultural fields were presented. The ISO 2631-1 (1997) and 2631-5 (2004) methodologies were used to evaluate typical WBV levels on this tractor using A(8), VDV(8), Q7 and Q8 screening ratios and R index. The results obtained from these standards showed that all of the examined machines produced vibration levels below the exposure limit values (ELV), however about 30% of them caused vibration exposures that exceeded exposure action values (EAV). Furthermore, all of the examined cases had the severity category (SC) of 3 or 4, which means that the health hazard associated with the examined operations is negligible or marginal. However conducting thorough experiments with more machines involved and with different working conditions and research on actions to reduce vibration levels are recommended. The recommended studies should include regular grading of agricultural tractors and machines and training of operators on how to use them in order to reduce the transmitted vibrations.

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Appendix

Calculation of WRMS (Arms), Q7 and Q8:

```
fs= ;
%sampling frequency
aw=[];
%measured and weighted data
must be entered in this vector
N=numel(aw);
M=fs;
aw=[aw.^2];
for k=1:(N-fs+1)
MTVV(k)=0;
for i=k:(fs+k-1)
MTVV(k)=MTVV(k)+aw(i);
end
MTVV(k)=MTVV(k)/fs;
end
MTVV=max(MTVV)
AW=0;
for i=1:N
AW=AW+aw(i);
end
AW=AW/N;
Arms=AW^(1/2)
T=N/fs;
aw=[aw.^2];
AW=0;
for i=1:N
AW=AW+aw(i);
end
AW=AW/fs;
VDV=AW^(1/4)
Q7=MTVV/Arms
Q8=VDV/(Arms*T^(1/4))
```

Calculation of risk factor (R):

```
days= ;
%number of exposure days per year
C= ;
%static stress due to gravitational force (MPa)
B= ;
 %age at which the exposure started
ey= ;
%number of years of exposure
%Sui=6.75-0.066(b+i)
r=10;
%ratio of workday time to the time
of data acquisition
mk=0.015;
%empirical coefficient for x axis
m=0;
a=[];
%measured data of X axis
must be entered in this vector
n=numel(a);
if a(1)>a(2)
m=m+1;
b(m)=a(1);
end
for i=1:(n-2)
if(a(i+1)>a(i) & a(i+1)>a(i+2))
m=m+1;
b(m)=a(i+1);
end
end
if a(n)>a(n-1)
m=m+1;
b(m)=a(n);
end
c=[b.^6];
Dk=0;
for k=1:m
Dk=Dk+c(k);
end
Dk=Dk^(1/6);
Dkd=Dk*r^(1/6);
Xaxis=(Dkd*mk)^6;
mk=0.035;
%empirical coefficient for y axis
m=0;
a=[];
%measured data of Y axis
must be entered in this vector
n=numel(a);
if a(1)>a(2)
m=m+1;
b(m)=a(1);
end
```

```
for i=1:(n-2)
if(a(i+1)>a(i) & a(i+1)>a(i+2))
m=m+1;
b(m)=a(i+1);
end
end
if a(n)>a(n-1)
m=m+1;
b(m)=a(n);
end
c=[b.^6];
Dk=0;
for k=1:m
Dk=Dk+c(k);
end
Dk=Dk^(1/6);
Dkd=Dk*r^(1/6);
Yaxis=(Dkd*mk)^6;
mk=0.032;
% empirical coefficient for z axis
m=0;
a=[];
%measured data of Z axis
must be entered in this vector
n=numel(a);
if a(1)>a(2)
m=m+1;
b(m)=a(1);
end
for i=1:(n-2)
if(a(i+1)>a(i) & a(i+1)>a(i+2))
m=m+1;
b(m)=a(i+1);
end
end
if a(n)>a(n-1)
m=m+1;
b(m)=a(n);
end
c=[b.^6];
Dk=0;
for k=1:m
Dk=Dk+c(k);
end
Dk=Dk^(1/6);
Dkd=Dk*r^(1/6);
Zaxis=(Dkd*mk)^6;
Sed=(Xaxis+Yaxis+Zaxis)^(1/6)
q=(Sed*(days)^(1/6));
for i=1:ey
Su(i)=(q/(6.75-0.066*(B+i)-C))^6;
end
R=0;
for i=1:ey
R=R+Su(i);
end
R=R^(1/6)
```

Calculation of VDV:

```
s= ;
% sampling frequency
aw=[];
% measured and weighted data
must be entered in this vector
N=numel(aw);
aw=[aw.^4];
AW=0;
for i=1:N
AW=AW+aw(i);
end
AW=AW/fs;
VDV=AW^(1/4)
```

---

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