Study of the Influence of Speed and Type of Roads on Vibrations Transmitted to an Electric Tractor Driver

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Abstract. This article presents the results obtained following the experimental analysis of the whole-body vibrations transmitted by an electric tractor designed for two types of road and two different speeds recommended by ISO 2631/1 to the driver. The acquisition of experimental data is carried out with the Biometrics Data Log data acquisition and processing system and with the help of 3 triaxial accelerometers mounted on the seat, on the seatback, and on the tractor cab. Total vibration and acceleration values were obtained using Vats Nex Gen Ergonomics software.

Keywords: r.m.s weighted acceleration · electric tractor · Whole body vibrations · accelerometer · VATS · ISO 2631-1

1 Introduction

As technology develops, many drivers are exposed to whole-body vibration when driving different types of vehicles. Most of the exposure to whole-body vibration takes place in sitting positions while driving. In addition, whole-body vibrations are usually transmitted when the human body is in contact with vibrating surfaces (i.e. a driving seat, a seatback or a vehicle floor) [1].

Occupational exposure to whole-body vibration has been highlighted as one of the major occupational risk factors when driving an electric tractor on different roads. Due to the construction of the electric motor, this will generate less vibration during normal operations [2]. Numerous studies have been done on whole-body vibration, largely for classical agricultural tractors of various sizes [3–5], but much less specialized literature has dealt with the study of whole-body vibration in electric tractors.

In this article we aim to make an experimental analysis of the whole-body vibrations transmitted to the driver by an electric tractor designed for two types of road and two different speeds, recommended by ISO 2631/1 [6].

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Table 1. Specifications of tractor used for WBV evaluation.

Item	Specifications
Model	Electric Tractor TE-0
Power/Kw	28,8
Traction battery	A02-BAT2
Size [mm]	3330 (L)/2530 (H)/1530 (W)
Suspension system	Adjustable suspension seat (without axle or cab suspension)
Front tire pressure/kPa	750
Rear tire pressure/kPa	1220

Fig. 1. Carrying out experimental tests on terrain types according to the experimental protocol, at speeds of 6 and 12 km/h: a) straight terrain; b) uneven ground.

2 Experimental Protocol

For this study, the vertical vibrations transmitted to the driver were collected and evaluated using an electric tractor (TE-0), having the technical specifications presented in Table 1.

The equipment used is the Vibrations Analysis Tool Set (VATS), developed by Nex Gen Ergonomics [7]. VATS software is based on the ISO2631-1 standard which describes the procedures for assessing whole-body vibration. The equipment includes the MWX8 Data LOG device, which is a fully portable, programmable data acquisition unit of the Biometrics system [8], which is an data acquisition system based on wearable sensors, used for the acquisition and processing of biomechanical data [9], in various fields of research, such as: biomechanics, clinical medicine, rehabilitation, sports performance and ergonomics [10–17].

A driver (70 kg weight and 180 cm height) performed all field tests. He voluntarily participated in the experimental measurements after signing an informed consent, holding a driving license and being medically fit. The experimental tests were performed with traffic speeds of 6 km/h and 12 km/h, on 2 types of terrain belonging to the National Institute of Agricultural Machinery in Bucharest (Fig. 1). The tractor seat suspension is

Fig. 2. Mounting the tri-axial accelerometers on the surface of the tractor seat, on the seatback and on the cab floor at the support leg.

adjusted to the maximum height with a 10° suspension angle, and the driver's position describes a right angle of 90° with respect to the inclination of the seatback.

Accelerations along the three perpendicular axes (a_x, a_y, a_z) were measured simultaneously with the aid of 3 tri-axial accelerometers, mounted both on the seat and on the interface between the seat and the driver, on the seatback and on the floor of the tractor cab next to the support leg. The accelerations were frequency weighted using the weight curves W_k and W_d, obtaining the values of the accelerations a_{wx}, a_{wy} and a_{wz} according to ISO 2631-1 [6] (Fig. 2).

3 Results

Vibration exposure is defined in terms of intensity, duration and number of exposure intervals over time. Vibration evaluation is calculated using the weighted r.m.s value, acceleration defined as such [1, 18]:

$$a_w \text{r.m.s} = \left[\frac{1}{T} \int_0^T a_w^2(t) dt \right]^{1/2}$$

where, a_Wr.m.s: the root-mean-square (r.m.s), a_w(t): the frequency-weighted acceleration at time t, T: the measurement duration.

The total value of the vibration is defined by the expression:

$$a_{W_v} = \sqrt{k_x \, a_{W_x}^2 + k_y \, a_{W_y}^2 + \, k_z \, a_{W_z}^2}$$

where a_{Wx}, a_{Wy}, a_{Wz} correspond to the vibration values in the 3 orthogonal axes x, y and z; k_x, k_y and k_z are multiplying constants that depend on the measurement application.

Table 2 shows the r.m.s weighted acceleration values and peak values of the transmitted vibration accelerations for the two cases, while in Fig. 5 these values are plotted.

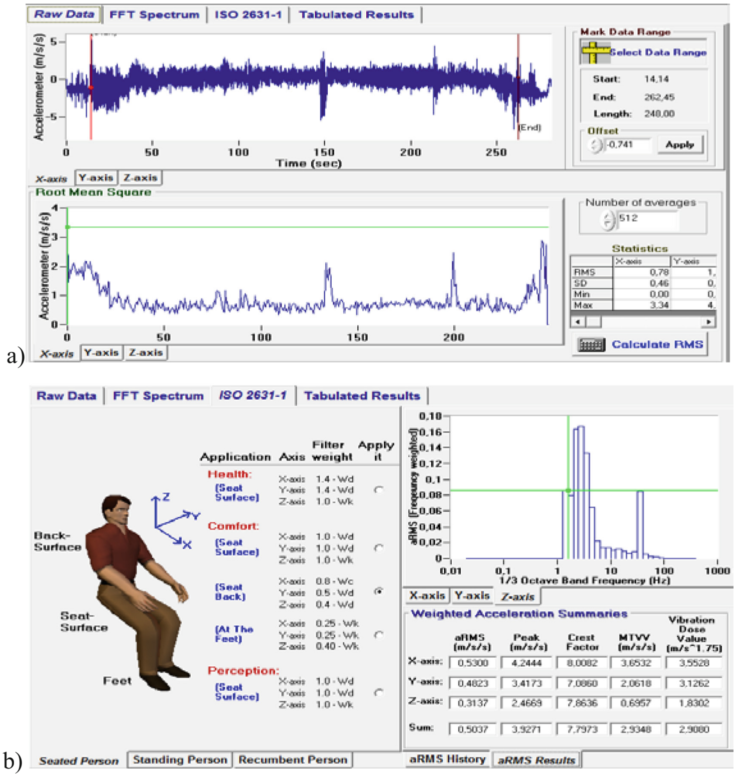

Fig. 3. a) r.m.s weighted acceleration variation on time during collecting data for Case I 1.b) Raw data and r.m.s weighted acceleration values, for Case I. 1, collected by ACL seat-back, rendered by VATS software.

4 Discussion

The comparative analysis of the graphs shows that WBV emission levels increase in proportion to the running speed of the electric tractor and the roughness of the road, and the growth rate was higher on the uneven road, while lower exposures were found on the paved/straight road. Figures 3, 4, a) and b) show that the type of road and the speed of travel had significant effects on the weighted rms accelerations, which increased with speed, and this trend was found more on the uneven road, due to specific roughness of this type of road/terrain.

For the seat-back ACL sensor, the maximum value recorded in Case I 1 is 0.3137 m/s^2, less than the value of 0.5136 m/s^2 recorded for experimental measurements with a conventional agricultural tractor, in time for Case I 2, the maximum value is 0.9394 m/s^2, also lower than the value 0.9894 m/s^2 recorded for the experimental measurements with a classic agricultural tractor in Article [19]. For the same sensor, for Case II 1 the maximum value is 0.4449 m/s^2, lower than the value 1.2370 m/s^2 recorded for a classic tractor, while for CASE II 2 the maximum value was 0.9146 m/s^2, lower than the value 1.7191 m/s^2 recorded in a similar case with a classic agricultural tractor.

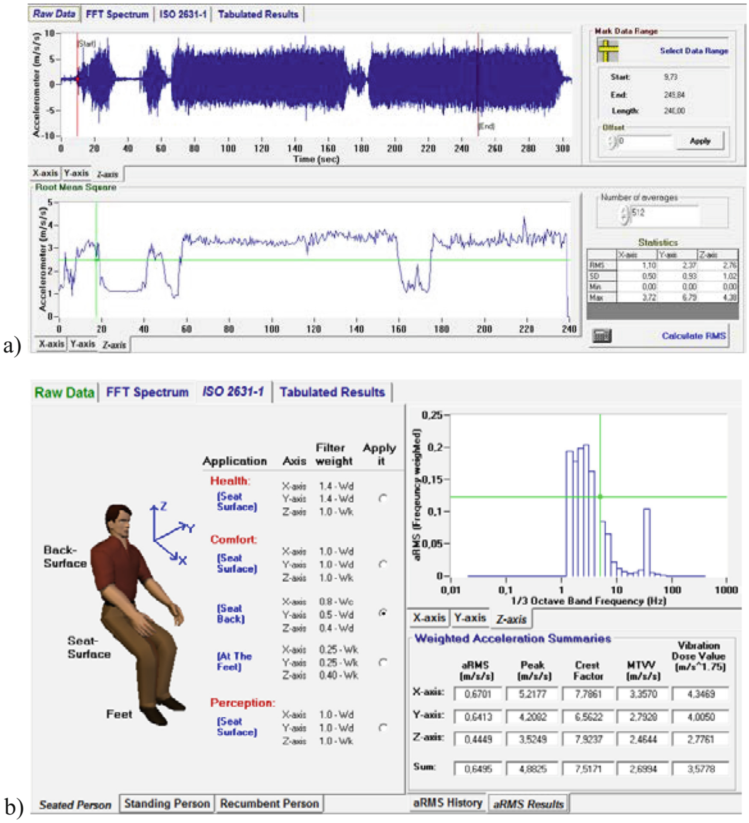

Fig. 4. a) r.m.s weighted acceleration variation on time during collecting data for Case II 1.b) Raw data and r.m.s weighted acceleration values, for Case II 1, collected by ACL seat-back, rendered by VATS software.

For the seat-surface ACL sensor, the maximum value recorded in Case I 1 is 0.6898 m/s^2, lower than the value 0.630 m/s^2 recorded for the experimental measurement with a classic agricultural tractor, while for Case I 2, the maximum value is 0.9477 m/s^2, also lower than the value of 1.024 m/s^2 recorded for classic agricultural tractor. For the same sensor, for Case II1 the maximum value is 0.7042 m/s^2, lower than the value 0.890 m/s^2 recorded for a classic tractor, while for CASE II 2 the maximum recorded value was 0.9146 m/s^2, less than 1.050 m/s^2 recorded in agricultural tractor and studied in [19].

Table 2. r.m.s weighted acceleration values and peaks values of vibration: Straight road and uneven road at a speed of 6 km/h and 12 km/h.

Cases	Position of accelerometer	Axis	aRMS [m/s/s]	Peak [m/s/s]
Case I. 1. Straight road at a speed of 6 km/h	Seat surface	X-axis	0,4356	3,4987
		Y-axis	0,4823	3,4173
		Z-axis	0,6898	3,6870
		Sum	0,9477	6,1247
	Seat back	X-axis	0,5300	4,2444
		Y-axis	0,4823	3,4173
		Z-axis	0,3137	2,4669
		Sum	0,5037	3,9271
	At the Feet	X-axis	0,3858	3,4605
		Y-axis	0,6913	3,6594
		Z-axis	0,6898	3,6870
		Sum	0,3396	1,9392
Case I. 2. Straight road at a speed of 12 km/h	Seat surface	X-axis	0,9457	5,1111
		Y-axis	0,7490	2,9585
		Z-axis	0,9736	6,7598
		Sum	1,1630	8,9761
	Seat back	X-axis	0,5133	6,2510
		Y-axis	0,7490	2,9585
		Z-axis	0,9394	4,4972
		Sum	0,9001	7,7586
	At the Feet	X-axis	0,7112	3,5670
		Y-axis	0,8662	4,9615
		Z-axis	0,9152	2,1970
		Sum	0,8913	3,1256
Case II. 1. Uneven road at a speed of 6 km/h	Seat surface	X-axis	0,4835	3,6351
		Y-axis	0,6413	4,2082
		Z-axis	0,7042	4,7978
		Sum	0,8025	7,3445

(*continued*)

Table 2. (*continued*)

Cases	Position of accelerometer	Axis	aRMS [m/s/s]	Peak [m/s/s]
	Seat back	X-axis	0,6701	5,2177
		Y-axis	0,6413	4,2082
		Z-axis	0,4449	3,5249
		Sum	0,6495	4,8825
	At the Feet	X-axis	0,6169	6,2245
		Y-axis	0,6307	6,1565
		Z-axis	0,6042	4,7978
		Sum	0,4830	2,9109
Case II. 2. Uneven road at a speed of 12 km/h	Seat surface	X-axis	0,8084	3,7984
		Y-axis	0,9943	6,6891
		Z-axis	0,9931	7,4689
		Sum	1,1065	9,7200
	Seat back	X-axis	0,8095	5,3078
		Y-axis	0,7943	3,2600
		Z-axis	0,9146	6,9757
		Sum	1,2437	6,0506
	At the Feet	X-axis	0,9524	6,0580
		Y-axis	0,9823	6,5366
		Z-axis	1,0987	7,6554
		Sum	1,1461	3,2780

For the ACL sensor at the feet (floor), the maximum value recorded in Case I 1 is 0.6898 m/s^2, lower than the value 0.747 m/s^2 recorded with a classic agricultural tractor, while for Case I 2, the maximum value is 0.9152 m/s^2, lower than the value 0.9894 m/s^2 recorded for the experimental measurements with a classic agricultural tractor. For the same sensor, for Case II1 the maximum value is 0.6042 m/s^2, less than the value 1.676 m/s^2 recorded for a classic tractor, while for CASE II 2 the maximum recorded value was 1.0987m/s^2, less than the value of 1.709 m/s^2 recorded in a case similar to a conventional agricultural tractor and studied in [19].

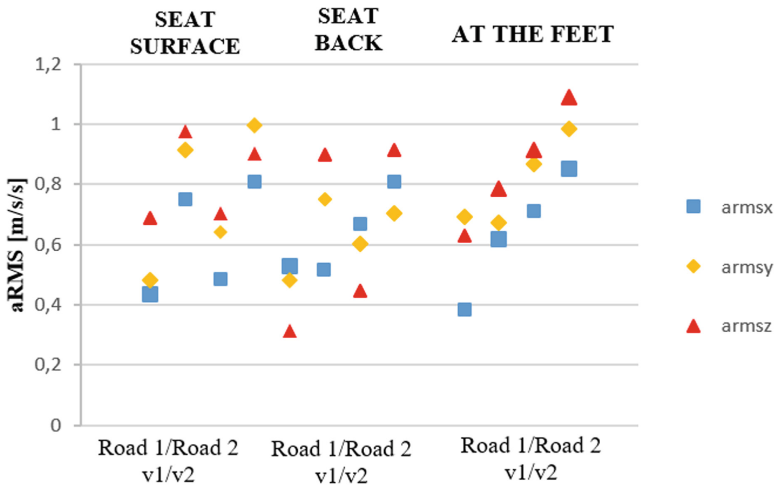

Fig. 5. Graphical representation of the r.m.s weighted acceleration values for both types of roads and both speeds for: a) ACL at the seat surface; b); ACL seatback; c) ACL at the feet

5 Conclusion

The objective of this paper was to analyze the driver's exposure to vibrations produced by the type and nature of the road, respectively the speed of traffic on an electric tractor. With the help of the Biometrics and VATS data acquisition and processing system, experimental data that provide a suggestive and complex picture of the human vibrations experienced by the driver during specific daily activities, in different conditions can be collected and processed rigorously. This study shows that in the case of an electric tractor, the intensity of these vibrations is reduced compared to the vibrations transmitted by a classic tractor.

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