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INFLUENCE OF THE ROAD TYPE ON THE WHOLE BODY VIBRATIONS TRANSMITTED TO THE DRIVER OF AN ELECTRIC TRACTOR

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Abstract: *Whole body vibration (WBV) is a potential condition leading to occupational diseases in tractor operators. A method of evaluating the vehicle's vibration reduction properties. One way to analyze the properties of the tractor in order of reducing the vibrations felt by the operator while driving, to improve comfort and safety, is to use electric tractors. The literature has confirmed that the emission levels of the WBV electric tractor depend very much on the nature of the operation per-formed, the speed parameter and the nature of the road. This study high-lights the influence of the combination of the speed (speed v1 = 5 km / h) of the electric tractor (model TE-0) and the roughness of the road surfaces (straight road, uneven road, rough road and plowed land). The acquisition of data during the experimental tests was done with the Biometrics software, and the processing and interpretation of the values of the accelerations produced, with the dedicated software Vats Nex Gen Ergonomics.*

Key words: *aRMS, electric tractor, WBV exposure, accelerometer, VATS, vibrations, ISO 2631-1.*

1. INTRODUCTION

The main cause of WBV production is the assembly consisting of the vehicle seat and the driver, but important aspects of transmitting vibrations are the seat back, hands and feet. Thus, European Union Directive 2002/44 / EC defines daily exposure limits to protect drivers from the adverse effects of vibration. To this end, various standards define some methods for assessing drivers' exposure to WBV and establish several Health Guidance Areas (HGCZ). This article aims to make a parallel of the evaluation of the vibrations of the human body described in the ISO 2631-1: 2008 standard in the context of the driving mode of the electric tractor [1]. In the analysis, we took into account different travel surface conditions and a constant speed specified in the standard [2]

The peculiarities of the vibratory process to which the driver is subjected are different depending on the environment. Agricultural tractors move on uneven surfaces, so they cause high levels of WBV. When the tractors are in operation on off road, the metal support assembly of the tractor takes over the vibrations produced by the engine and the contact with the type of surface of the ground [3]. Intense low vibration frequency (0.5 to 80 Hz) induced primarily by terrain unevenness can reduce comfort levels and increase the potential for musculoskeletal disorders (MSDs), especially back pain (LBP) [4 -5]. These higher magnitude vibration the emissions are assimilated by the driver while driving on a rough road, in exchange for driving on a smooth road [5-7]. The vibrations are distributed to the subject by means of the seat and are defined in the range of values of the measurement frequency by movement, speed and acceleration, depending on the type of tractor and the nature of the road. In analyzing and quantifying the effects of vibrations on the driver, the specialty literature define acceleration as an evaluation factor, and the analysis is done with the frequency weighting function. The analysis of the effects of the oscillating movements produced supposes the description of the three orthogonal directions of evaluation of the total vibrations felt by the driver, highlighting the longitudinal direction z (vertical), the x and y side directions, where the x direction indicates back-and-forth movements, and the y (lateral) direction indicates left-right movements (Fig. 1).

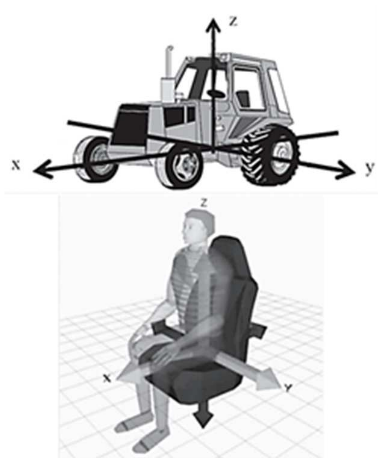


Fig. 1. Description of the 3 x, y, z evaluation directions for an agricultural vehicle and tractor driver [5]

In this study our purpose is to perform an experimental analysis of the vibrations of the whole body transmitted to the driver by an electric tractor designed for four types of road and a constant running speed recommended by ISO 2631/1.

2. EXPERIMETAL PROTOCOL

From the sample of subjects were selected anthropometric data of a healthy man, 35 years old, with a height of 1.75 m and a body weight of 80 kg, and was involved in conducting the trials by concluding a participation agreement. The tests were performed at the National Institute of Agricultural Machinery in Bucharest, which has 4 types of terrain: straight, uneven, unprocessed and plowed. Experimental measurements were performed at a speed set by 5 km/h.

For this study, the vertical vibrations transmitted to the driver were collected and evaluated using an electric tractor (TE-0), having the technical specifications shown in Table 1. The suspension of the vehicle seat is described in the tractor data sheet, irregular and position. The established inclination defined by the driver and the back of the seat is 90 °.

Table 1

Specifications of electric 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. 2. Description of the protocol regarding the experimental tests performed on the 4 types of road at constant speed of 5 km / h: a) straight terrain; b) uneven ground; c) uncultivated land; d) plowed land

The equipment used is Vibrations Analysis Tool Set (VATS), a Nex Gen Ergonomics product [8]. One of the components of the equipment used for acquisition and processing the data, Biometrics, [9] is MWX8 Data LOG which is a wearable unit [9], which helps to collect and process biomechanical data transferred from the wearable sensors [10]. The system is well known and often used in many research fields: biomechanics, rehabilitation, robotics, sports performance, pre and post-surgery behavior of musculoskeletal system, monitoring daily activities [10-21].

VATS software is developed based on ISO2631-1 the procedure that characterizes the way of analyzing the oscillating movements of the human body [20]. Accelerations along the three perpendicular axes (axle, ay, az) were measured simultaneously using 3 tri-axial accelerometers, mounted at the seat and at the interface between the seat and the driver, at the seat back and on the cab floor tractor, near the support leg. The accelerations were frequency weighted using the weight curves Wk and Wd, respectively, obtaining the values of the accelerations a_{wx}, a_{wy} and a_{wz} according ISO 2631-1.

Fig. 3. Mounting of tri-axial accelerometers on the surface of the tractor seat, on the seat back and the base of the cab near the driver's support leg.

3. RESULTS

The analysis of the mechanical vibrations produced involves a measurement of the weighted average acceleration of the square root (RMS) on the x, y and z axis measured at the driver's seat. The acquisition rate sampling frequency was 1250 Hz. The discussions will be highlighted as follows:

a_{wi} is the filtered RMS acceleration used to compare the acceleration measurements along the three axes (i = x, y, z).

a_W is calculated according to the equation.

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

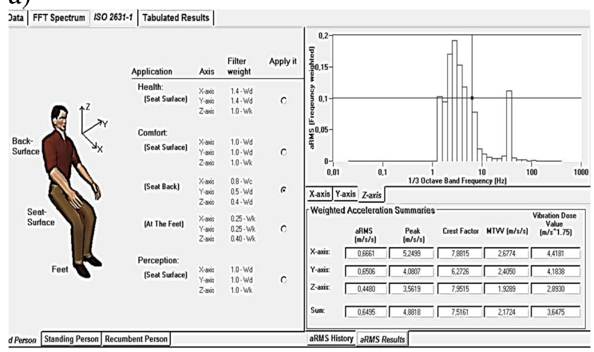
Where, awr.m.s: the root-mean-square (r.m.s), aw (t): the frequency-weighted acceleration at time t, T: the measurement time.

The total value of the oscillation movement is defined by the expression:

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

Where a_{Wx}, a_{Wy}, a_{Wz} correspond to the vibration values in the 3 orthogonal ax-es x, y and z is a multiplication factor described in ISO which is conditioned by position of purchase (chair, backrest or legs) and the required axis (x, y or z). In terms of safety, ISO 2631 recommends k = 1.4 for X and Y axes, and k = 1 for the Z axis.

a)



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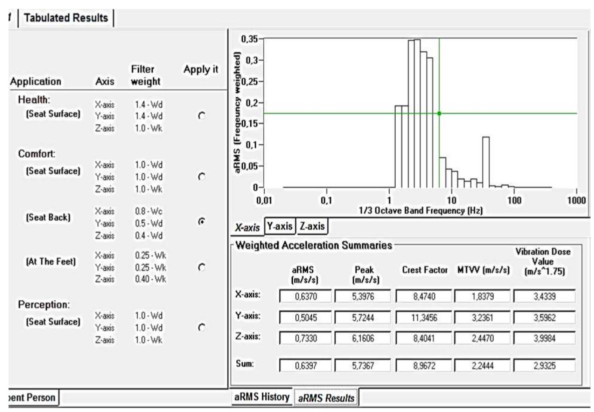

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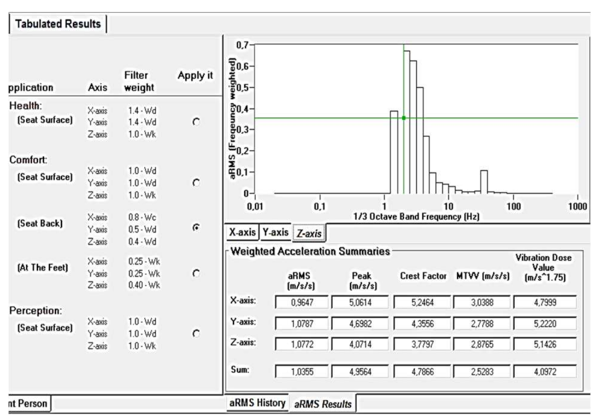

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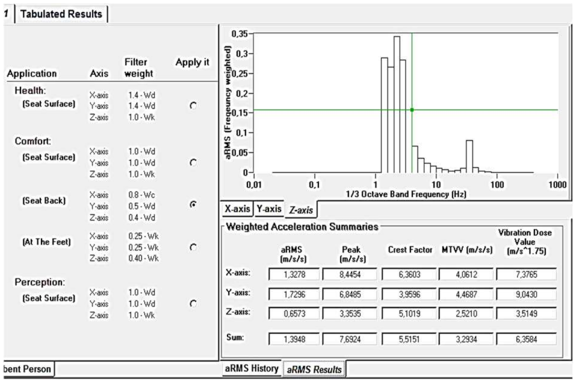

Fig. 4. a) aRMS variation on time during collecting data for Case I – straight road; b) Raw data and aRMS, for Case II – uneven road, c) Raw data and aRMS, for Case III – uncultivated land; d) Raw data and aRMS, for Case IV – arable land; collected by ACL seat-back, for constant speed of 5 km/h.

Table 2

aRMS and peaks values of vibration: Straight road, uneven road, rough road, and arable land at a speed of 5 km/h.

Cases	Position of accelerometer	Axis	aRMS [m/s/s]	Peak [m/s/s]
Case I. Straight road at a speed of 5 km/h	Seat surface	X-axis	0.4356	3.4987
		Y-axis	0.4823	3.4173
		Z-axis	0.5898	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 II Uneven road at a speed of 5 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 III Uncultivated land at a speed of 5 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
	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	0.7842	4.7978
		Sum	0.6830	2.9109
Case IV Arable land at a speed of 5 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

Making an analysis of the results of the graphical values, namely the characteristics of the comfort values for either one frequency (x, y, z), are described in a narrow range of values of the sampling frequency for each type of road, conditioned by the elastic particulars of electric tractor, not accidentally chosen conditioned by road or speed that facilitates an approach to amplitude. Thus, the values of vibration amplitudes are defined by the degree of roughness and the nature of the type of road on which the experimental tests were performed, with a constant speed.

The following diagram shows the graphical representations of the aRMS values of the vibration accelerations transmitted to the 3 ACL sensors, for the 4 cases studied.

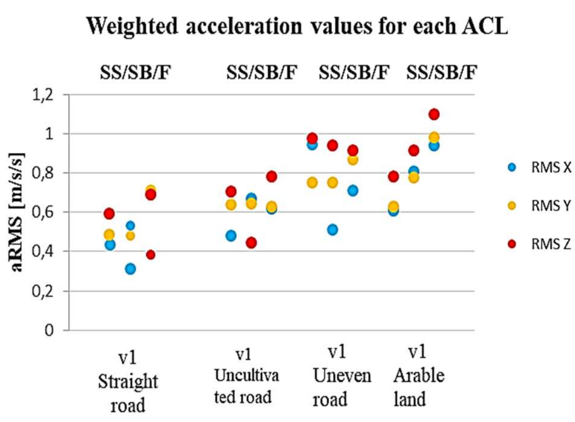

Fig. 5. Graphical representation of the aRMS values for the 4 types of roads at a constant speed of 5 km / h, for: a) ACL on the seat surface; b); ACL Rear; c) ACL foot

4. DISCUSSION

Figure 4, a), b), c) and d) show that the type of road had significant effects on the weighted r.m.s accelerations, which increased depending on the roughness of the road, while the speed parameter remaining constant. Thus, it can be distinguished in Table 2 and Fig.5, generally, the maximum dose of arms, which the driver felt during experimental tests, rendered by the mounted accelerometer sensors are smaller on X-axis medium values on Y-axis and bigger on Z- axis.

For the seat-surface ACL sensor, the values of a_{rms} on Z direction increase from 0.5898 m/s^2 in Case I, to 0.7042 m/s^2 in Case III, and to 0.9736 m/s^2 in Case II and 0.9931 m/s^2 in Case IV.

For the seat-back ACL sensor, the values recorded on Z axis vary from 0.3137 m/s^2 in Case I, to 0.4449 m/s^2 in Case III, increasing to 0.9394 m/s^2 in Case II and to 0.991 m/s^2 in Case IV. For the feet ACL sensor, the values of a_{rms} on Z direction increase from 0.6898 m/s^2 in Case I, to 0.7842 m/s^2 in Case III, to 0.9152 m/s^2 in Case II and 1.0987 m/s^2 in Case IV.

The most unfavorable types of road, from the point of view of whole body vibrations affecting the driver, are those corresponding to Case II and Case IV. For the same type of road, we can observe that the a_{rms} values are smaller for seat-back ACL, they increase for seat ACL and they are bigger for feet ACL.

Similar variations are reported for the sum of a_{rms} on each ACL sensor.

5. CONCLUSIONS

The objective of this study was to analyze the driver's exposure to the vibrations produced by the type and nature of the road, to the speed of traffic on an electric tractor. With the help of the Biometrics and VATS data acquisition and processing system, the experimental data were collected and processed rigorously, providing a suggestive and complex image of the human vibrations borne by the car operator during specific daily activities.

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Studiul influenței tipului de drum asupra vibrațiilor transmise unui sofer de tractor electric

Rezumat: Vibrațiile întregului corp (WBV) reprezintă unul dintre factorii de risc care determină apariția bolilor profesionale la conducătorii auto de tractoare agricole. O modalitate de evaluare a proprietăților vehiculului în ceea ce privește diminuarea vibrațiilor resimțite de operator în timpul mersului, pentru îmbunătățirea confortului și siguranței, este utilizarea tractoarelor electrice. Literatura de specialitate a confirmat că nivelurile de emisie ale tractorului electric WBV depend foarte mult de natura operațiunii efectuate, parametrul de viteză, precum și natura căii de rulare. Acest studiu subliniază influența combinației dintre viteza (viteza v_1=5 km/h) a tractorului electric (model TE-0) și rugozitatea suprafețelor de drum (drum drept, drum denivelat, drum neprelucrat și teren arat). Achizitionarea datelor in timpul efectuarii testelor experimentale s-a facut cu softul Biometrics, iar prelucrarea si interpretarea valorilor acceleratiilor produse, cu softul dedicat Vats Nex Gen Ergonomics.

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