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EVALUATION OF WHOLE-BODY VIBRATIONS AND COMFORT STATE OF TRACTOR DRIVER FOR DIFFERENT TYPES OF TERRAIN AND SPEEDS

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Abstract: *The long exposure of the human body to mechanical vibrations is a risk factor in terms of health and comfort of the driver being influenced by biomechanical variables that determine the intensity of vibration, frequency and amplitude. The aim of this study is to carry out an experimental investigation to assess the comfort state associated with different types of terrain and traffic speeds of a tractor. The levels of vibration produced during the experimental tests are evaluated using 3 tri-axial accelerometers mounted on driver's seat, on back seat at the spine level and on the floor of tractor cab, under the driver's support leg. The collected data are processed with the help of Vats Nex Gen Ergonomics software, and the methods for measuring the whole-body vibrations is based on the international standard ISO 2631-1.*

Key words: *whole-body vibration, comfort, accelerometer, tractor, VATS, ISO 2631-1.*

1. INTRODUCTION

The vibrations transmitted by the speed, by the geometry and characteristics of the type of road to the driver, through the category of vehicle with predefined technical specifications of the seat and seat back, affect the comfort of driving, and can have a detrimental effect on the health of the driver [1].

Numerous studies on human responses to whole-body vibration have been presented in the literature [1-18], and these objectives range from identifying risk factors that affect vibration discomfort to health problems that occur due to human exposure to vibration [3-5]. The driver of a vehicle is constantly exposed to mechanical vibrations, caused by uneven road surfaces and oscillations of vehicle components. These factors reduce the feeling of comfort and can be quite harmful to the occupant of the vehicle. The human body is a complex mechanical system and more sensitive to certain frequencies of vibrations on surfaces such as floors, chairs, armrests, whose frequency varies from 8 Hz to 1000 Hz, inducing certain movements known as vibration accelerations [6]

The frequency weighting for comfort reactions of the human body in vibration environments can be seen in Table 1.

Table 1

Comfort reactions to vibration environments [6]

Wheighted rms acceleration (m/s^2)	Subjective response
Less than 0.315 m/s^2	Comfortable
0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
0.5 m/s^2 – 1 m/s^2	Fairly uncomfortable
0.8 m/s^2 – 1.6 m/s^2	Uncomfortable
1.25 m/s^2 – 2.5 m/s^2	Very uncomfortable
Greater than 2 m/s^2	Extremely uncomfortable

Vibrations influence the human body in various ways, because there are frequencies which influence in a negative way different segments of the body. The response to a vibration exposure depends in particular on the frequency, amplitude and duration of exposure [7]. More recent studies have focused on studying the effects of vibration on the driver and on its health when making measurements on different road surfaces [8, 9, 10] at different vehicle speeds [11, 12, 13]. Reference articles describing the exposure of whole body vibrations to mechanical shocks, as well as the evaluation of vibration attenuation using tri-axial accelerometers, have been studied in [14, 15, 16].

The purpose of this paper is to study the comfort of the tractor driver caused by the whole-body vibrations developed during four experimental tests, depending on land type and the vehicule speed, quantified by means Root Mean Square weighted accelerations (aRMS).

2.1. The experimental protocol

A healthy male subjects aged 25 years, with height of 1.80 m and body mass 75 kg, participated voluntarily in performing the experimental measurements after signing an informed consent. The experimental tests were performed in the inner courtyard of the Faculty of Agronomy, which has two types of land: straight, asphalted road and arable land. The experimental measurements were made with the traffic speeds: 5 km/h and 10 km/h.

The vehicle used is a medium power tractor, type New Holland TD5010, equipped with a 37.3 kw, (50 hp) diesel engine at 2800 rpm, with direct injection and electric start. The wide range of use of the tractor is ensured by the independent or synchronous power take-off and by the wide range of speeds achieved by the 12- forward and reverse speed gearbox, doubled by means of a reducer. The suspension of the tractor seat is the specified one in the technical data sheet of the tractor, unadjusted, and the position of the driver describes an angle of 90º in relation to the inclination of the seat-back.

The following cases were considered:

Case I. 1. Straight road – speed: 5 km/h;
Case I. 2. Straight road – speed: 10 km/h;
Case II. 1. Arable land – speed: 5 km/h;
Case II. 2. Arable land – speed: 10 km/h.

Fig. 1. Carrying out experimental tests on straight terrain and arable ground, according to the experimental protocol, at speeds of 5 and 10 km / h

2.2. Equipment and measurements

The equipment used to measure the vibrations of the entire body of a driver sitting in a seat is Vibrations Analysis Tool Set (VATS), developed by Nex Gen Ergonomics [19], in order to enable researchers to obtain vibration data and compare them to the various standards. VATS software is based on ISO2631-1 which describes procedures for the evaluation of whole-body vibrations. The equipment includes the MWX8 Data LOG device, which is a fully portable, programmable data acquisition unit found in the Biometrics system. Biometrics is a system of wearable sensors, used for the acquisition and processing of biomechanical data [20], in various fields of research, such as: biomechanics, clinical medicine, rehabilitation, sports performance and ergonomics [21-27]. Data LOG collects data from accelerometers with a maximum sampling rate of 20,000Hz / channel, and then the data is downloaded to a computer for data analysis. Data for x-axis (anterior-posterior direction), y-axis (medial-lateral direction) and z-axis (vertical direction) of accelerometers are collected simultaneously.

a) b) c)

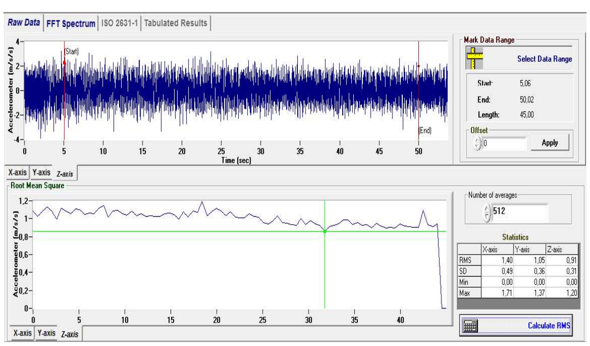
Fig. 2. a) Accelerometer ACL 300, b) Single ACL and mounted on the pad, c) Data log device.

The equipment consists of 3 tri-axial accelerometers ACL 300, type S2A-16G-MF, with 16G precision, 3-axis offset and adjusted sensitivity, incorporated in a flexible disc and mounted in accordance with ISO 2631-1, in regarding the specifications, location and direction of measurement. First accelerometer is mounted on the seat surface between the driver and the seat. The second is mounted in a flexible rubber pad that folds on the seat back and on the driver's back, while the third is mounted on the floor of the tractor cab under the driver's support leg to allow him to take over all signals produced by the vibrations that occur during the tests, including the tractor's own vibrations.

Fig. 3. Mounting the tri axial accelerometers on the tractor seat surface, on the seat back, respectively on the cab floor at the support leg

3.RESULTS

In accordance with ISO 2631-1 standard, which present methods and values of risk assessment at the level of whole body vibrations, we will make an analysis of the tractor driver by means the whole body vibrations developed during the four tests. Root Mean Square weighted accelerations (aRMS) values are a static measure of the magnitude of a weighted signal transmitted by the vibration produced during each set of experimental tests.



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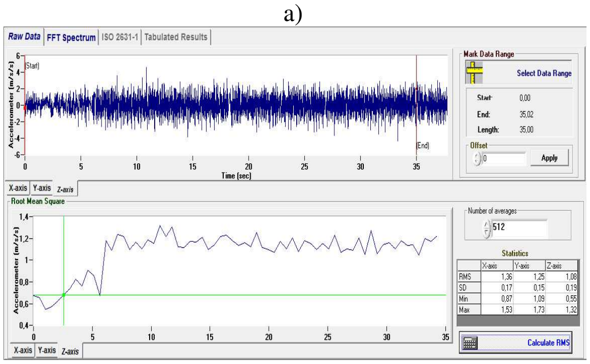

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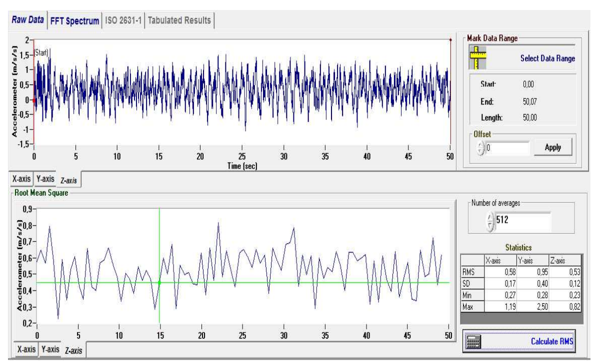
Fig. 4. Raw data and aRMS collected on straight road by the ACL mounted on the floor surface at the feet level; a) speed 5 km / h; b) speed 10 km / h

Vibration analysis on the human driver who performs a series of experimental tests described above and uses special sensors to measure the vibrations of the human body, is materialized by the detailed study on the impact of the health of the human body exposed to vibrations under certain working conditions. The conclusions will be drawn from the processing of all experimental data collected from the three sensors using VATS software, based on the ISO 2631 standard.

In Figures 5, 6 and 7, the row data collected by the three ACL mounted on seat surface, seat back and cab floor, as well as the corresponding graphs of aRMS on z axis for comfort zone, on arable land for a tractor speed equal to 5 km/h are presented, while in Table 2 the aRMS and peaks values are shown.

Similar diagrams, graphs and tables of aRMS values and peaks are obtained for all experimental tests.



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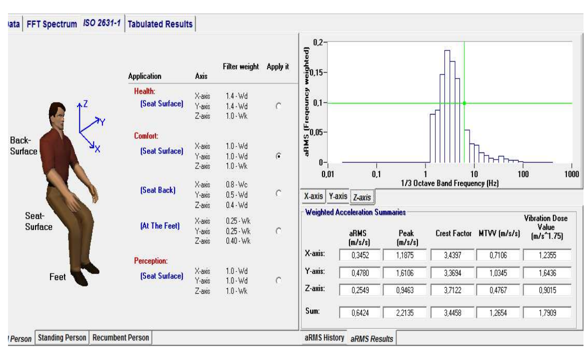

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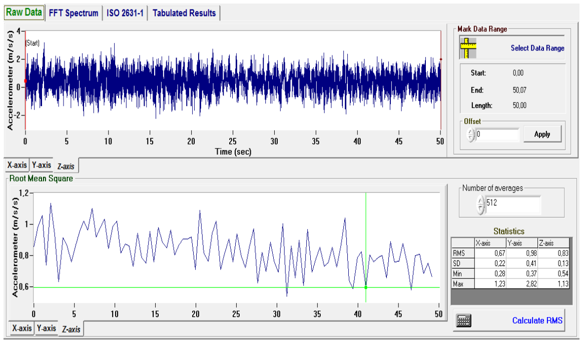
Fig. 5. a) Row data collected by ACL 1 (seat surface) and b) the graph of aRMS, on Z axis for comfort zone on arable land for a tractor speed of 5 km / h



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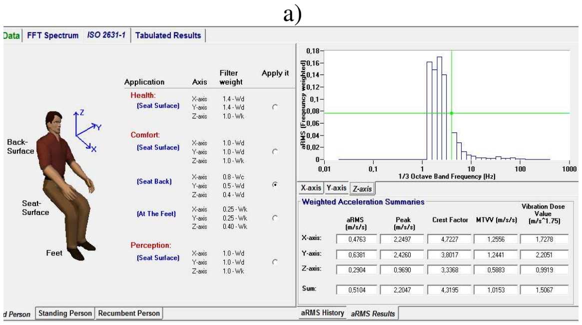

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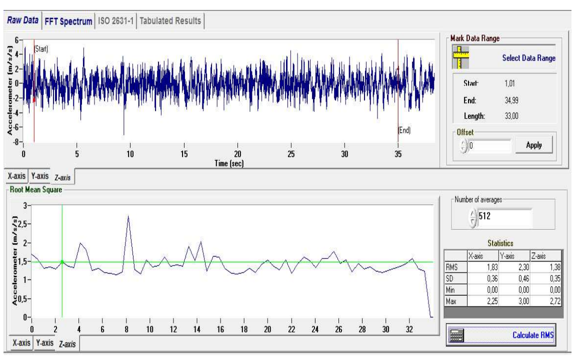
Fig. 6. a)Row data collected by ACL 2 (seat back) and b) the graph of aRMS, on Z axis for comfort zone; for arable land and tractor speed of 5 km / h.



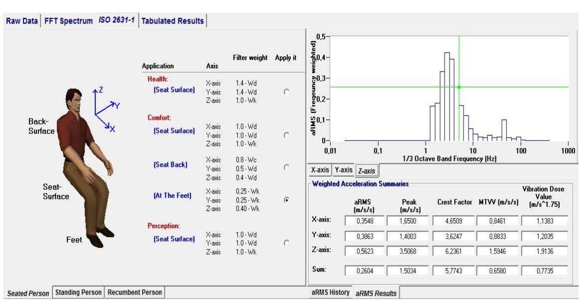


Fig. 7. Row data collected by ACL 3 (feet) and b) the graph of aRMS, on Z axis for comfort zone for arable land and tractor speed of 5 km / h.

Table 2

Values of aRMSand peaks of vibration

Cases	Position accelerometer	Axis	aRMS [m/s^2]	Peak [m/s^2]
Case I. 1. Straight road at a speed of 5 km / h	**Seat surface**	**X-axis**	0,1374	0,8823
		Y-axis	0,1728	0,7071
		Z-axis	0,2098	0,9797
		Sum	0.3046	1.4960
	Seat back	**X-axis**	0,2262	1,0691
		Y-axis	0,1925	0,8530
		Z-axis	0,2349	1,3038
		Sum	0.2255	1.0888
	At the Feet	**X-axis**	0,2543	0,9769
		Y-axis	0,4689	1,3926
		Z-axis	0,5303	1,7332
		Sum	0.2506	0.8133
Case I. 2. Straight road at a speed of 10 km / h	**Seat surface**	**X-axis**	0,2016	0,9238
		Y-axis	0,2106	0,9048
		Z-axis	0,5385	2,3828
		Sum	0.6123	2.7110
	Seat back	**X-axis**	0,4329	3,0041
		Y-axis	0,2695	1,3271
		Z-axis	0,3499	2,3031
		Sum	0.3971	2.6580
	At the Feet	**X-axis**	0,3029	1,4269
		Y-axis	0,3580	1,9720
		Z-axis	0,4421	2,0052
		Sum	0.2602	1.0061
Case II. 1. Arable land at a speed of 5 km / h	**Seat surface**	**X-axis**	0,3452	1,1875
		Y-axis	0,4780	1,6106
		Z-axis	0,2549	0,9463
		Sum	0.6424	2.2135
	Seat back	**X-axis**	0,4763	2,2497
		Y-axis	0,6381	2,4260
		Z-axis	0,2904	0,9690
		Sum	0.5104	2.2047
	At the Feet	**X-axis**	0,3548	1,6500
		Y-axis	0,3863	1,4003
		Z-axis	0,5623	3,5068
		Sum	0.2604	1.5034
Case II. 2. Arable land at a speed of 10 km / h	**Seat surface**	**X-axis**	0,7766	2,5857
		Y-axis	0,8142	2,7278
		Z-axis	0,9719	6,9437
		Sum	1,4868	78956
	Seat back	**X-axis**	1,0141	4,1573
		Y-axis	1,1418	,3,9397
		Z-axis	0,9852	5,6388
	At the Feet	**X-axis**	0,4684	2,0767
		Y-axis	0,5838	2,0967
		Z-axis	1,2325	5,0150

		Sum	0.5273	2,1374

4.DISCUSSIONS

The present study is used to analyze the whole-body vibrations affecting drivers on a tractor traveling with two different speeds on two different road surfaces. Based on the processed experimental data collected during the four tests, the aRMS and the peak values corresponding to the three accelerometers and to the three axes of coordinates for each accelerometer, the comfort of tractor driver can be studied.

Following the analysis of the graphs obtained, in relation to the weighting of the frequency for the comfort reactions of the human body in the vibration environments presented in Table 1, for experimental tests performed on a straight road, for the first case, the driver's comfort reaction is comfortable, and for the second case, the value of aRMS acceleration increases and frames the comfort reaction as uncomfortable. For experimental tests performed on arable land, depending on the increase in traffic speed, the driver's comfort reaction becomes uncomfortable, so that the aRMS acceleration values and the frequency weight increase significantly, so the driver is significantly exposed to a high level of vibration presenting a risk of health and safety.

Based on the results in Table 2, comparing the aRMS values recorded on each axis of the accelerometers mounted on the seat, back and leg, for each case studied, it can be stated that:

For case I.1 (straight road; speed = 5 km/h) it is found that maximum value of aRMS is recorded for seat surface and feet on Z axis: 0.2098 m/s^2, respectively 0.5303 m/s^2, while for seat back, is recorded on Y axis 0.1925 m/s^2.

For case I.2 (straight road; speed = 10 km/h) maximum value of aRMS is recorded for the seat surface and feet on Z axis: 0.5383 m/s^2, respectively 0.4421 m/s^2, while for seat back, is recorded on X axis 0.4329 m/s^2.

For case II.1 (arable land; speed = 5 km/h) maximum value of the RMS is recorded for seat surface and feet on Z axis: 0.4780 m/s^2, respectively 0.5623 m/s^2, while for seat back, is recorded on Y axis 0.6381 m/s^2.

For case II.2 (arable land; speed = 10 km/ h) it is found that maximum value of RMS is recorded for seat surface and feet on Z axis: 0.9719 m/s^2, respectively 1.2325 m/s^2, while for seat back, is recorded on Y axis 1.1418 m/s^2.

The values representing the sums of aRMS (Sum) increase with increasing speed on the two types of road, for each of the three accelerometers.

For the speed of 5 km / h, Sum aRMS values recorded by the accelerometers for the seat, back and feet accelerometers, respectively 0.3046 m/s^2, 0.2255 m/s^2, 0.2506 m/s^2 are lower than the Sum aRMS values for the speed of 10 km/h, 0.6123 m/s^2, 0.3971 m/s^2, 0.2602 m/s^2, for the straight road.

For arable land, for speeds of 5 km/h, Sum aRMS values recorded by the seat, back and feet accelerometers, 0.6424 m/s^2, 0.5104 m/s^2 and 0.2604 m/s^2, respectively, are lower than Sum aRMS values for speed of 10 km / h, and anme, 1.4868 m/s^2, 2.3540 m/s^2 and, respectively, 0.5273 m/s^2.

For speeds of 5 km/h, the values of Sum aRMS on the straight road, recorded by the accelerometers for seat surface, 0.3046 m/ ^{2}, for seat back, 0.6123 m/s^2 and for the feet, 0.2255 m/s2, are lower than those recorded in the field arable, namely, respectively, 0.6424 m/s^2, 0.5104 m/s^2, 0.2604 m/s^2.

For the speed of 10 km / h, the values of Sum aRMS on straight road, recorded by the accelerometers for seat, back and feet, respectively, 0.6123 m/s^2, 0.3971 m/s^2, 0.2122 m/s^2, on straight road are lower than the values amount of aRMS on arable land 1.4868 m s^2, 2.3540 m/s^2, 0.5273 m/s^2.

In conclusion, on arable land the values of aRMS are higher than the values recorded on the straight road.

According to table 1 regarding the comfort state of the human body subjected to vibrations on bth categories of roads and both speeds analyzed, for the 3 sensors mounted on seat surface, seat back and feet, the following situations are presented in Table 3:

Table 3

The comfort state of tractor driver subjected to vibrations

Type of road	Position of accelerometer	Speed [km/h]	Condition	Description
Straight road	Seat Surface	5 km/h	Less than 0.315 m/s^2	Comfortable
		10 km/h	0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
	Seat Back	5 km/h	Less than 0.315 m/s^2	Comfortable
		10 km/h	0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
	Feet	5 km/h	0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
		10 km/h	0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
Arable land	Seat Surface	5 km/h	0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
		10 km/h	0.5 m/s^2 – 1 m/s^2	Fairly uncomfortable
	Seat Back	5 km/h	0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
		10 km/h	0.8 m/s^2 – 1.6 m/s^2	Uncomfortable
	Feet	5 km/h	0.315 m/s^2 – 0.63 m/s^2	A little uncomfortable
		10 km/h	0.5 m/s^2 – 1 m/s^2	Fairly uncomfortable

5. CONCLUSION

Evaluation of human responses to whole-body vibration was obtained by direct measurements at the tractor seat under real operating conditions according to the experimental protocol and the standard method of vibration collection (ISO Standard 2631-1). The raw data were then applied to the Vibration Analysis Toolkit (VATS) and analyzed according to the vibration standard. Vibration data were analyzed for comfort at the seat surface and health precaution area for each participant in the experimental tests. The results of the analysis presented in this article, concerning human responses and comfort state to whole-body vibration, allow to take into account the effects that occur while driving the tractor on different types of terrain and different traffic speeds. The effects of Root-Mean-Square vibration acceleration values (aRMS) presented in the experimental cases is considerable for the evolution of the driver's state of health in terms of values achieved in the normal operating mode of the tractor on arable land, as opposed to straight terrain; this significant increase in vibration intensity depending on the increasing traffic speed.

6. ACKNOWLEDGMENTS

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EVALUAREA VIBRAȚIILOR INTERIORE ALE CORPULUI ȘI A CONFORTULUI CONDUCĂTORULUI DE TRACTOR PENTRU DIFERITE TIPURI DE TEREN ȘI VITEZE

Rezumat: Expunerea îndelungată a corpului uman la vibrațiile mecanice este un factor de risc în ceea ce privește sănătatea și confortul șoferului, fiind influențat de variabile biomecanice care determină intensitatea vibrațiilor, frecvenței și amplitudinii. Scopul acestui studiu este de a efectua o investigație experimentală pentru a evalua starea de confort asociată cu diferite tipuri de teren și viteza de trafic a unui tractor. Nivelurile de vibrații produse în timpul testelor experimentale sunt evaluate folosind 3 accelerometre tri-axiale montate pe scaunul șoferului, pe bancheta din spate la nivelul coloanei vertebrale și pe podeaua cabinei tractorului, sub piciorul de sprijin al șoferului. Datele colectate sunt prelucrate cu ajutorul software-ului Vats Nex Gen Ergonomics, iar metodele de măsurare a vibrațiilor întregului corp se bazează pe standardul internațional ISO 2631-1.

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