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STUDY OF THE EFFECTS OF VIBRATION TRANSMISSION IN OPERATORS OF ELECTRIC TRACTORS DRIVEN AT CONSTANT SPEED ON DIFFERENT TYPES OF ROADS

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Abstract: This scientific article presents a detailed analysis of the transmission of whole–body vibration (WBV) to electric tractor drivers while driving on two distinct types of terrain: ploughed and straight road, at a constant driving speed. Biometrics triaxial accelerometer sensors, mounted at the driver's back and seat level on the tractor seat, were used to perform this evaluation. The data collected were processed using Vats Nex Gen Ergonomics software and the whole–body vibration measurement methods are based on the international standard ISO 2631–1. The main purpose was to highlight the maximum vibration values (rms) on the 2 types of terrain at constant speed transmitted to the driver during experimental tests carried out at the National Institute of Research – Development for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest using a TE–0 prototype electric tractor.

Keywords: WBV exposure, electric tractor, accelerometer sensors, VATS, ISO 2631–1, comfort

INTRODUCTION

Operator comfort and health are of prime importance when operating large agricultural tractor vehicles, and these can be strongly influenced by the effects of vibration. Vibration, although it may seem at first glance to be a minor problem, has a significant impact on the health of the tractor driver. These vibrations can lead to a range of problems for the operator, including increased fatigue, back pain and other musculoskeletal conditions. In addition, reduced comfort in the tractor cab can affect the operator's ability to concentrate and work efficiently, *(Griffin, 1990)*. WBV can have a significant impact on operator comfort and health, and therefore understanding how these are influenced by speed and the nature of the road type is essential to improve operational performance and safety *(Oncescu et al., 2021; Oncescu et al., 2022; Nawayseh and Griffin, 2012)*. Electric tractor travel speed can be a determining factor in the transmission of vibrations to the driver. At higher speeds, vibrations can become more intense and disturbing for the driver. It is therefore necessary to investigate how vibrations vary with speed in order to identify the upper limits of speed at which the operator can work comfortably and safely *(Eger et al., 2011; Loutridis et al., 2011; Wijaya et al., 2003)*. Also, the nature of the road type, whether paved roads or agricultural land, can have a significant impact on vibration transmission. Arable land or roads with uneven surfaces can amplify the effects of vibration, which can lead to greater operator exposure to the risk of fatigue and muscle pain *(Aisyah et al., 2017; Kabir et al., 2017; Velmurugan et al., 2012)*.

MATERIALS AND METHODS

EXPERIMENTAL PROTOCOL

The subject selected for this research was chosen based on precise anthropometric criteria, with a height of 1.75 meters and a body weight of 80 kilograms. He was an integral part of the research process by signing an agreement to participate in the study. The experiments were carried out at the National Institute of Agricultural Machinery in Bucharest, a suitable setting for vibration transmission studies in an agricultural context. The infrastructure of the Institute has four distinct types of terrain: straight, uneven, unimproved and ploughed, thus providing a variety of conditions for vibration transmission analysis, for this study, we used only 2 types of road. The experimental tests were performed at a constant speed of 5 km/h to ensure a framework of comparability and consistency of the collected data. This is essential for assessing how road speed influences vibration transmission to the driver.

For this study, vertical vibrations transmitted to the driver were collected and evaluated using an electric tractor (TE–0). The technical specifications of this vehicle are described in Figure 1. In addition, it is important to note that the suspension of the tractor seat, which is in an irregular position, and the inclination set at 90 degrees between the driver and the seat backrest are key aspects of the experiment, as they significantly influence how the vibrations are felt by the driver.

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

Figure 1 – Specifications of the electric tractor used for the evaluation WBV

Figure 2 – Description of the protocol for the experimental tests carried out on the 2 types of roads at constant speed of 5 km/h: a) straight terrain; b) arable land.

Equipment and measurements

To perform these measurements, we used the Vibration Analysis Tool Set (VATS), developed by Nex Gen Ergonomics (VATS™, http://www.nexgenergo.com/ergonomic s/vats.html). The main purpose of this toolkit is to enable researchers to collect vibration data and evaluate them in accordance with relevant standards.

The VATS software is based on the ISO2631–1 standard, which provides detailed procedures for whole–body vibration assessment.

The central component of this equipment is the MWX8 Data LOG device, which serves as a programmable and portable data acquisition unit. This device is part of the Biometrics system, which specialises in biomechanical data acquisition and processing *(User Manual, http://www.biometricsltd.com)*. Biometrics is used in a variety of research areas such as biomechanics, clinical medicine, rehabilitation, sports performance and ergonomics *(Tarnita, 2016; Tarnita et al., 2019, Gherman et al., 2019; Tarnita et al., 2016; Vaida et al., 2020)*.

Data LOG has the ability to collect data from accelerometers with a maximum sampling rate of 20,000 Hz per channel. It simultaneously records data for the x–axis (antero–posterior direction), y–axis (medio–lateral direction) and z–axis (vertical direction) of the accelerometers.

Figure 3. a) Accelerometer ACL 300, b) Single ACL and mounted on the pad, c) Data log device.

The equipment used in the experimental tests was designed to accurately measure vibration transmission to the seated driver. It consists of two tri–axial sensors, namely ACL 300 accelerometers, with detailed specifications and essential functionalities for data collection: Type: S2A–16G–MF, accuracy: 16G, allowing measurements on 3 axes, which means they are able to detect vibrations in multiple directions. Adjustable sensitivity, allowing them to be adjusted to suit the specific requirements of the study in accordance with the specifications of ISO 2631–1, which defines procedures for whole–body vibration assessment. The first accelerator was mounted directly on the seat surface, between the driver and the seat. This arrangement allows direct measurement of vibrations transmitted through the tractor seat to the driver. The second accelerometer was placed in a flexible rubber mount designed to fit on the seat backrest and the driver's back. This system was chosen to allow the accelerometer to capture all vibration signals, including general tractor vibration, which can be felt through the seat back and driver's back.

Figure 4 – Mounting of tri–axial accelerometers on the surface of the tractor seat and on the seat back

RESULTS

The analysis carried out in this study follows the stiffness and standards set by ISO 2631–1, which provides methodologies and values for assessing whole–body vibration risk. The aim of this analysis is to assess the impact of vibration transmission on the tractor driver during the two experimental tests.

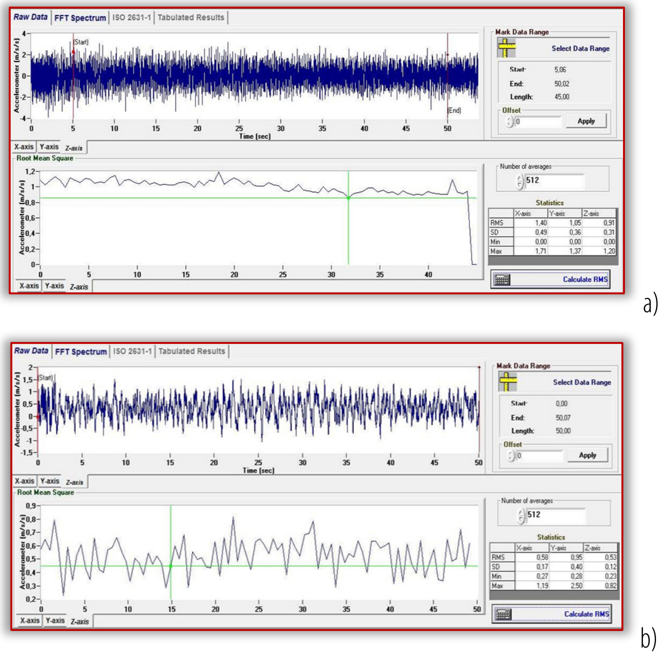

Figure 5 – Raw data and aRMS collected, a) on straight road and b) arable land by the ACL mounted seat surface speed 5 km / h

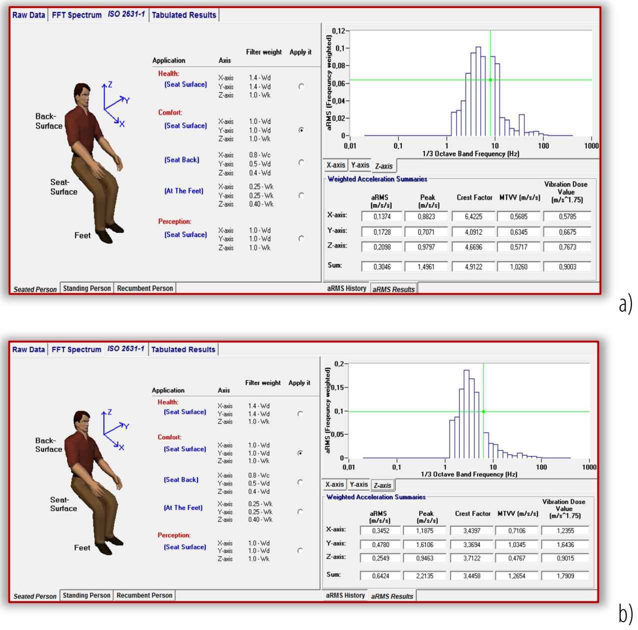

Figure 6 – Row data collected by ACL (seat surface) and the graph of aRMS, on Z axis for comfort zone for: a) straight road and b) arable land and tractor speed of 5 km / h.

Mechanical vibration analysis is a key component of this study and involves measuring weighted root mean square (RMS) accelerometer on the three directional axes: X–axis, Y–axis and Z–axis. This measurement is carried out at the driver's seat and is a fundamental way of quantifying and characterising the vibrations transmitted to the driver during the experimental tests. The RMS measurement is intended to provide an objective assessment of the level of mechanical vibration experienced by the driver.

This indicator is essential to quantify the vibration intensity and to compare these measurements with safety and comfort standards or limits specified in the literature or in relevant regulations. Using the VATS vibration processing software, we performed a detailed scientific analysis to assess the impact of vibration transmission on the driver in the electric tractor seat under different experimental conditions. This process included the generation of a series of graphs that represent key aspects of our study and provide visual data for vibration transmission analysis and interpretation.

Table 1. Values of aRMS and peaks of vibration

Cases	Position accelerometer	Axis	aRMS [m/s²]	Peak[m/s²]
Case I. 1. Straight road at a speed of 5km / 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
Case II. Arable land at a speed of 5 km / h	Seat surface	X–axis	0,3452	1,1875
		Y–axis	0,4780	0,6106
		Z–axis	0,2549	0,9463
		Sum	0.6424	2.2135
	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

DISCUSSION

Figure 6, a) and b), represents a statement from the perspective of the impact of vibration transmission on the driver on the electric tractor. This observation shows that the type of road, specifically its roughness, has a significant effect on the weighted vibration values, while the driving speed remains constant. The figures show that with increasing road roughness, the weighted vibration values (aRMS) increased significantly.

Table 2. The comfort state of tractor driver subjected to vibrations (International Organization for Standardization, 1997)

Type of road	Position of accelerometer	Speed	Condition	Description
Straight road	Seat Surface	5 km/h	Less than 0.315 m/s²	Comfortable
	Seat Back	5 km/h	Less than 0.315 m/s²	Comfortable
Arable land	Seat Surface	5 km/h	0.315 m/s² – 0.63 m/s²	A little uncomfortable
	Seat Back	5 km/h	0.315 m/s² – 0.63 m/s²	A little uncomfortable

Table 1 shows the values of RMS accelerations and peaks for the two accelerometer sensors calculated with the VATS software. This may be related to the fact that a rougher road generates more vibrations or more intense vibrations as the vehicle travels over the surface. These increased vibrations can have a negative impact on driver comfort and health. According to Table 2 on the state of comfort of the human body subjected to vibrations on both categories of road speed analysed, for the 2 sensors mounted on the seat surface and on the seat back, the following situations are presented.

Although the roughness of the road had a significant impact on the vibrations, it is interesting to note that the travel speed remained constant in these experiments. This is important because it allows us to isolate the effect of road roughness on vibration transmission. In other words, we can conclude that the observed variations in aRMS are mainly attributable to road characteristics and not to speed.

CONCLUSION

This study was a comprehensive evaluation of human responses to whole–body vibration generated while driving an electric tractor in a real operating environment. This approach allowed us to assess comfort and vibration levels in the health caution zone for each of the experimental test participants. The results obtained in this study provided insight into how whole–body vibration can influence driver comfort and health. Terrain roughness had a significant effect on vibration levels. Arable land, compared to straight land, generated higher vibration levels. High levels of accelerometer weighted root mean square (aRMS), especially in experimental cases with arable terrain and high speeds, can have a significant impact on driver health. This can include increased fatigue, discomfort and the potential for long–term health issues.

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