VIBRATION ASSESSMENT OF TRACTOR OPERATOR BASED ON VIBRATION SIGNALS
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ΑΞΙΟΛΟΓΗΣΗ ΒΑΣΕΙ ΣΗΜΑΤΩΝ ΔΟΝΗΣΗΣ ΤΩΝ ΚΡΑΔΑΣΜΩΝ ΠΟΥ ΔΕΧΕΤΑΙ Ο ΧΕΙΡΙΣΤΗΣ ΤΟΥ ΕΛΚΥΣΤΗΡΑ

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ABSTRACT

Operator fatigue during work with agricultural machinery is a significant factor contributing to fatal accidents in Greece. Workers operating agricultural machinery, especially those working with tractors and off-road machines, constitute one of the most hazard-prone groups due to mechanical vibrations transmitted from the ground to the operators' seats. Operators of tractors and off-road machines are exposed to intense mechanical vibrations, underscoring the importance of cumulatively calculating permitted working hours. This work presents a study that was conducted at the Laboratory of Safety and Ergonomics of Agricultural Machinery, Department of Agriculture – Agrotechnology, Faculty of Agricultural Sciences, University of Thessaly, in order to evaluate the vibrations generated when operators work with agricultural tractors and off-road machinery. The results of the study showed that the highest levels of vibration occurred during disc harrowing operation, particularly when the disc harrow moved vertically or at an angle of 30° to the ploughing direction. For seed bed preparation, it is recommended to use tractors equipped with a suspension system for the operator's cabin and a seat with an adjustable range of perceived vibration. Additionally, to prevent fatigue or health problems for tractor operators, it is advisable to limit permitted working hours to fewer than 8 hours per day.

ΠΕΡΙΛΗΨΗ

Η κόπωση του χειριστή κατά τη διάρκεια της εργασίας με γεωργικά μηχανήματα είναι ένα σημαντικός παράγοντας ο οποίος συμβάλει στην πρόκληση πολλών θανατηφόρων ατυχημάτων στην Ελλάδα. Οι Χειριστές γεωργικών μηχανημάτων, ιδιαίτερα εκείνοι που χειρίζονται ελκυστήρες και μηχανήματα εκτός δρόμου, αποτελούν μια από τις πιο επιρρεπείς σε κινδύνους ομάδες χειριστών λόγω των μηχανικών κραδασμών που μεταδίδονται από το έδαφος στα καθίσματα τους. Οι χειριστές ελκυστήρων και μηχανημάτων εκτός δρόμου εκτίθενται σε έντονους μηχανικούς κραδασμούς, υπογραμμίζοντας τη σημασία του σωρευτικού υπολογισμού των επιτρεπόμενων ωρών εργασίας. Η εργασία αυτή παρουσιάζει μια μελέτη που διεξήχθη στο Εργαστήριο Ασφάλειας και Εργονομίας Αγροτικών Μηχανημάτων του Τμήματος Γεωπονίας – Αγροτεχνολογίας, της Σχολή Γεωπονικών Επιστημών του Πανεπιστημίου Θεσσαλίας και έχει σαν σκοπό την αξιολόγηση των δονήσεων που δημιουργούνται όταν οι χειριστές εργάζονται με γεωργικούς ελκυστήρες και οδικά μηχανήματα. Τα αποτελέσματα της μελέτης έδειξαν ότι τα υψηλότερα επίπεδα κραδασμών εμφανίστηκαν κατά την εκτέλεση εργασιών με την χρήση δισκοσβάρνας προσαρμοσμένης σε γεωργικό ελκυστήρα, ιδιαίτερα όταν η δισκοσβάρνα κινούνταν κάθετα ή υπό γωνία 30° ως προς την κατεύθυνση του οργώματος. Για την προετοιμασία της σποράς, συνιστάται η χρήση ελκυστήρα εξοπλισμένου με σύστημα ανάρτησης της καμπίνας του χειριστή και κάθισμα με ρυθμιζόμενο αντικραδασμικό σύστημα. Επιπλέον, για να αποφευχθεί η κόπωση ή τα προβλήματα υγείας των χειριστών του ελκυστήρα, συνιστάται ο περιορισμός των επιτρεπόμενων ωρών εργασίας σε λιγότερες από 8 ώρες την ημέρα.

INTRODUCTION

Agricultural workers operating tractors face exposure to whole-body vibrations, a challenge influenced by factors such as the type of mounted farm implements, tractor speed, and field conditions. These vibrations, characterized by multiaxis translational and rotational inputs affecting various body areas, traverse through the buttocks, torso, and spinal column (*Amari et al., 2015; Scarlett et al., 2007*). Operating in such an environment leads to fatigue, impacting ride comfort and contributing to health issues like metabolic disorders, cardiovascular problems, and nervous system complications (*Rahmatalla et al., 2023; Loutridis et al., 2011*).

Farmers dedicate many hours to agricultural activities throughout the year, with tractor usage reaching up to 14 hours on the busiest days (*Sorainen et al., 1998*). This prolonged engagement exposes them to work-related hazards, notably whole-body vibration *(Biriș et al., 2022; Singh et al., 2021; Vlăduţ et al., 2013*). Unlike the industrial sector, whole-body vibration exposure in tractor drivers is intricate due to variable factors during fieldwork (*Singh et al., 2018*). Tractor-mounted implements and interactions with the terrain contribute to the whole-body vibration experienced by drivers (*Singh et al., 2018; Kumar et al., 2001*). Vibrations are transmitted to the operator's body through points of contact such as the tractor floor, operational levers, seat pan, seat backrest, and steering wheel, potentially causing discomfort and health issues (*Cheng et al., 2022; Dmitrieva and Myakishev, 2019; Village et al., 2012*).

Modern tractors are equipped with specialized shock-absorbing systems, primarily integrated into the support bases of the control cabin and seat. The purpose of these systems is to absorb generated mechanical vibrations as much as possible, thereby minimizing their impact on the operator's body (Marsili et al., 2002). It is noteworthy that each part or organ of the human body has a range of natural resonance frequencies, and these frequencies inherently affect the permissible duration of exposure to mechanical vibrations.

Many studies (*Loutridis et al., 2011*) indicate that tractor drivers often experience vibration levels surpassing the exposure action value (0.5 m/s2) outlined in Directive 2002/44/EU (*E.U. Directive, 2002*). Elevated vibration exposure is closely associated with various health conditions, including musculoskeletal hazards (e.g., back pain) (*Griffin, 2007*), fatigue (e.g., muscle tiredness) (*Loutridis et al., 2011*), and nervous system problems (e.g., carpal tunnel syndrome) (*Goglia et al., 2003*).

Driver performance is also affected by tractor vibrations (Village et al., 2012). Research indicates that off-road situations expose individuals to more severe whole-body vibrations compared to on-road scenarios (*Adam et al., 2020*), potentially surpassing recommended health exposure limits (*ISO 2631-1, 1997*). Elevated whole-body vibration exposure is a significant occupational risk factor associated with lower back pain among tractor drivers (*Singh et al., 2019*). Furthermore, whole-body vibration can induce muscle elongation and shortening, leading to increased muscular tension and fatigue (*Ritzmann et al., 2010*). Of particular concern are low-frequency vibrations (1-10 Hz), which significantly impact tractor operators due to uneven terrain and imbalanced engine parts (*Nawayseh, et al., 2020*). The human body's sensitivity to low-frequency vibrations, coupled with extended exposures, results in rapid weariness, reduced functioning, and potential harm to the operator's health (*Singh et al., 2021*). Whole-body vibration directly affects driver attentiveness, increasing physical and mental strain, leading to fatigue and drowsiness (*Bhuiyan et al., 2022*).

Exposure of a body part or organ to high-level vibrations at their resonance frequencies can lead to extremely unpleasant symptoms, especially chronic health conditions.

The main physical characteristics of the mechanical vibrations measured during experimental tests include their intensity, measured in m/s^2, and their frequency, measured in Hz. It is crucial that the generated vibrations do not surpass specific permissible values. These values are established to safeguard operators and are determined in accordance with EU guidelines, specifically the ISO 2631/97/Amd 1:2010 standard and Directive 89/391/EEC (consolidated in 2008)!

Measures aimed at safeguarding operators from mechanical vibration include the installation of safety cabins on modern tractors, which are mounted on hydraulic shock absorbers. It is imperative that the seat is capable of damping vibrations and is in good condition to effectively protect the operator during work. The manner in which auxiliary agricultural machinery is connected to the tractor is a crucial factor, as it significantly influences the intensity of the generated vibrations. Other factors that significantly affect operator fatigue include the speed of movement during work, the condition of the ground, and the operator's sitting posture. In modern tractors, in addition to adjusting the vibration range, there is the option to rotate the operator's seat 15° to the right and left. This feature assists operators when they need to turn their bodies to look backward and control the attached agricultural machinery (*Brienza et al., 1996*).

This study aimed to identify, record, and analyse the factors that contribute to tractor operator fatigue under real-time conditions. Additionally, the study sought to measure the magnitudes of mechanical vibrations and frequencies that occur in the control cabin of agricultural tractors during field movement.

MATERIALS AND METHODS

The experimental determination of whole-body vibrations on the operator's seat of agricultural tractors was conducted on uncultivated land containing straw remnants from previous cultivation. The moisture content of the soil was 20% (dry basis), and this level remained constant throughout the tests. The soil had a sandy-clay-loam (SCL) mechanical composition, and the ambient temperature during the experiments was 20°C.
For the experimental tests, the LAMBORGHINI Premium 950 tractor was used. This tractor boasts a power output of 70 kW and is equipped with a mechanical system for adjusting the seat's vibration range, hydrostatic steering, and 4-wheel drive (4WD). The speed was maintained within the range of 5.5 – 6.0 km/h throughout the tests. Ploughing was conducted prior to disc harrowing to prepare the seedbed. The disc harrow used for the experimental tests was a secondary tillage implement with a working width of 3.20 m, featuring a total of 33 discs, each with a diameter of 0.50 m, and operating at a depth of 0.11 m.

The study was focused on the whole-body vibrations generated during all agricultural operations carried out with the aforementioned agricultural tools on the operator's seat.

To determine the accelerations of mechanical vibrations within the control cabin of the tractor, experimental tests were conducted with a towed disc harrow attached. Sensors placed under the operator's seat recorded the impacts of mechanical vibrations. The results of the experimental tests were analysed to determine the magnitude of the interactions among all factors that cause unpleasant symptoms in operators and to establish the permitted working time.

The vibrations were captured using an electronic recording unit known as VIBROTEST 60 from Bruel & Kjaer Vibro Company. This unit is equipped with adjustable sensors secured under the operator's seat using magnets, capable of recording signals for all magnitudes of vibration. This is to ensure better visualization and assessment of the vibrations affecting the operator. Throughout the tests, the range of vibrations and the corresponding frequencies were recorded. The device was calibrated to record 1600 values, for each 250 m field stretch, capturing vibration accelerations in m/s² and frequencies in Hz ranging from 0 – 100 Hz at intervals of 0.3125 Hz. Three replicates were performed for each measurement. The experimental tests were conducted along three movement paths: a) parallel to ploughing, b) at an angle of 30° degrees to ploughing, and c) perpendicular to ploughing. From these measurements, the average was calculated and the maximum value of the averages was taken for each direction. The measurements were conducted according to international standards ISO 2631-1-5/1997, ISO 10326-2:2022 and ISO 8041-1:2017. These standards define the permissible limits for daily exposure to vibrations known as or A(8), which corresponds to a vibration acceleration of 0.50 m/s², and the vibration dose value (VDV) of 9.1 m/s^1.75.

The values obtained were analysed using a computer and specialized software designed to create graphs. The graphs depict vibration accelerations in units of m/s² versus frequencies in units of Hz.

Test measurements

The maximum vibration values were analysed in three axes: X (vibrations in the horizontal longitudinal axis in the direction of tractor motion), Y (vibrations in the horizontal transverse axis in the direction of tractor motion), and Z (vibrations in the vertical axis in the direction of tractor motion). Based on the experimental tests, the averages of the maximum values obtained in the three directions, X_{max}, Y_{max}, and Z_{max} were recorded, and the daily vibration dose was calculated.

Calculation of the daily vibration dose or A(8)

The calculation of the daily vibration dose (DVD), internationally denoted as A(8), is determined by taking the highest mean acceleration value of the three repetitions in the X, Y, and Z directions. This is shown in equations (1) to (3).

The highest value of DVD or A(8) in m/s² was taken into account during the calculation (*Griffin et al., 2006*) of the permissible daily working hours (PDWH).

$$A_x(8) = 1{,}4_{awx}\sqrt{\frac{T_{\exp}}{T_0}} \quad [\text{m/s}^2] \tag{1}$$

$$A_y(8) = 1{,}4_{awy}\sqrt{\frac{T_{\exp}}{T_0}} \text{ [m/s}^2\text{]} \quad (2)$$

$$A_z(8) = 1{,}0_{awz}\sqrt{\frac{T_{\exp}}{T_0}} \text{ [m/s}^2\text{]} \quad (3)$$

where:

T_{exp} = 6 h the desired duration of daily work (ISO, 1997)

T_o = 8 h the duration of daily work,

α_{wx}, α_{wy}, α_{wz} = the maximum acceleration values (m/s^2) in the x, y, and z axes, respectively.

The daily vibration dose was determined by the highest values of $A_x(8)$, $A_y(8)$, and $A_z(8)$. The daily vibration dose, A(8), is calculated from the root mean square (rms) values of the vibration accelerations in all directions. This value is proportional to the magnitude of the vibration acceleration and the square root of its duration. The highest daily vibration dose (DVD), denoted as A(8), is determined according to equation (4) (*Griffin et al., 2006*).

$$A(8) = \max\left[A_x(8), A_y(8), A_z(8)\right] \text{ [m/s}^2\text{]} \quad (4)$$

The accelerometers were placed in the same position as the operator, for example, under the operator's seat. Their orientation was aligned with the directions of the vibrations. The recording was continuous during the 6 hours of daily working time of exposure (T_{exp} = 6 h).

The calculation of the daily vibration dose or A (8) is given (*Griffin et. al., 2006*), by equation (5):

$$A_1(8) = k_l\sqrt{\frac{1}{8}a_{wl}^2 \times 6} = k_l\frac{\sqrt{3}}{2}a_{wl} \text{ [m/s}^2\text{]} \quad (5)$$

where:

a_{wl} = the maximum value of the averages of vibration accelerations (r.m.s.), in direction *i*, for a desired daily working duration (6 hours).

k_l = human sensitivity factor, equal to 1.4 for the x and y directions and 1.0 for the z direction.

Calculation of the operator's permitted daily working hours

The calculation of permitted working hours for agricultural tractor operators is based on guidelines provided by European Standard EN 14253: 2003 + A1: 2007 and ISO 2631-1-5/1997. According to these standards, the upper limit of the tolerable permissible acceleration of vibration at the operator's seat, above which personal protective measures are required for up to eight (8) hours of work, is determined as: A(8) = 0,50 m/s^2 for T_0 = 8 hours of work.

The calculations took into account the permissible vibration acceleration, which is lower than A(8) = 0,45 m/s^2 for T_0 = 8 hours of work eliminating the need for additional measures. Therefore, the calculation of permissible working hours is given by equation (6) and is a function of the permissible value of the daily vibration dose (A8), the desired working hours T_0 and the maximum value of the daily vibration dose. This maximum value is obtained from the maximum accelerations of the vibrations in each direction (x, y, and z) on the operator's seat (ISO, 2631-1-5: 1997).

$$T_e = \frac{A^2(8) \times T_0}{A_{\max}^2(8)} \text{ [h]} \quad (6)$$

where:

T_e was measured in hours

A^2_{max} (8) = m/s^2, the maximum value of the daily vibration dose from the three directions x, y, and z,

A^2 (8) = 0.45 m/s^2, the allowable daily vibration dose at which operator protection measures are not required.

T_0 = 8 hours

Te = allowed working hours/day

If the daily vibration dose is Ai (8) > 0.45 m/s^2, then additional measures must be taken to protect the operator's health.

RESULTS

Determination of the daily vibration dose A(8) and the operator's working hours with the Lamborghini premium 950 tractor with disc harrow was performed.

Test No.1 Lamborghini premium 950 tractor with disc harrow, 1st pass on ploughed ground, movement parallel to ploughing, Tractor speed = 8.0 km/h.

From Table 1, for movement parallel to ploughing (1st pass), it can be seen that the developed accelerations α_W = m/s² of the vibrations in the three directions X_{max}, Y_{max}, and Z_{max}, are at low levels <0.5m/s². Therefore, the permissible working hours can be more than 8 hours per day. The maximum value was observed in the Z direction, α_w = 0.326 m/s², and the value of the daily vibration dose (DVD) in the X direction is A(8) = 0.297 m/s².

Table 1

Values of the daily vibration dose (DDI) and the allowable working hours of agricultural tractor operators

Vibration axis	Max mean values	Frequencies	DDI values A(8)	Allowed working hours	Vibrations comparison	Vibration change percentage
	[α_w = m/s²]	[Hz]	[m/s²]	[h]		[%]
X	0.245	1.56	**0.297**	**>8**	X→Y	51.2*
Y	0.162	1.88	0.197	–	Z→Y	101.2*
Z	**0.326**	2.19	0.282	–	Z→X	33.0*

* The rates of change of the vibrations are obtained for the x-axis ((0.245-0.162)/0.162)*100 = 51.2, for the y-axis ((0.326-0.162)/0.162)*100 = 101.2, and for the z-axis ((0.326-0.245)/0.245)*100 = 33, respectively.

Test No.2 Lamborghini premium 950 tractor with disc harrow, 2nd pass on ploughed ground, movement parallel to the ploughing, Tractor speed = 8.0 km/h.

From Table 2, for movement parallel to the ploughing (2nd pass), it can be seen that the developed accelerations α_W = m/s² of the vibrations in the three directions X_{max}, Y_{max}, Z_{max}, are at low levels <0.5 m/s². Therefore, the permissible working hours can be more than 8 hours per day. The maximum value is found in the Z direction, α_W = 0.376 m/s², and the value of the daily vibration dose (DVD) in the Z direction is A(8) = 0.326 m/s².

Table 2

Values of the daily vibration dose (DDI) and the allowable working hours of agricultural tractor operators

Vibration axis	Max mean values	Frequencies	DDI values A(8)	Allowed working hours	Vibrations comparison	Vibration change percentage
	[α_w = m/s²]	[Hz]	[m/s²]	[h]		[%]
X	0.145	3.44	0.176	–	Y→X	37.3
Y	0.199	1.25	0.241	–	Z→Y	89.0
Z	**0.376**	2.19	**0.326**	**>8**	Z→X	159.3

Test No.3 Lamborghini premium 950 tractor with disc harrow, on dry ploughed ground, movement parallel to the ploughing, Tractor speed = 8.0 km/h.

From Table 3, for movement parallel to ploughing on dry soil, it is seen that the developed accelerations α_W = m/s² of the vibrations in the three directions X_{max}, Y_{max}, Z_{max}, are at high levels >0.5 m/s². Therefore, the permissible working hours not exceed 8 hours per day, specifically 4:07 hours. The maximum value is found in the Z direction, α_W = 0.729 m/s², and the value of the daily vibration dose (DVD) in the Z direction is A(8) = 0.631 m/s².

Table 3

Values of the daily vibration dose (DDI) and the allowable working hours of agricultural tractor operators

Vibration Axis	Max mean values	Frequencies	DDI values A(8)	Allowed working hours	Vibrations comparison	Vibration change percentage
	[α_w = m/s^2]	[Hz]	[m/s^2]	[h]		[%]
X	0.350	1.88	0.424	—	Y→X	40.3
Y	0.491	1.88	0.595	—	Z→Y	48.5
Z	**0.729**	2.50	**0.631**	**4:07**	Z→X	108.3

Test No.4 Lamborghini premium 950 tractor with disc harrow, on dry ploughed ground, movement perpendicular to the ploughing, Tractor speed = 8.0 km/h.

From Table 4, for movement perpendicular to the ploughing, it can be seen that the developed accelerations α_w = m/s2 of the vibrations in the three directions X_{max}, Y_{max}, and Z_{max}, are at high levels >0.5 m/s^2. Therefore, the allowable working hours must not exceed 8 hours per day, specifically 1:16 hours. The maximum value is found in the Z direction, α_w = 1.364 m/s^2, and the value of the daily vibration dose (DVD) in the Z direction is A(8) = 1.181 m/s^2.

Table 4

Values of the daily vibration dose (DDI) and the allowable working hours of agricultural tractor operators

Vibration axis	Max mean values	Frequencies	DDI values A(8)	Allowed working hours	Vibrations comparison	Vibration change percentage
	[α_w = m/s^2]	[Hz]	[m/s^2]	[h]		[%]
X	0.810	2.81	0.982	—	X→Y	10.6
Y	0.732	6.56	0.887	—	Z→Y	86.4
Z	**1.364**	2.19	**1.181**	**1:16**	Z→X	68.4

Test No.5 Lamborghini premium 950 tractor with disc harrow, on dry ploughed ground, driving at an angle of 30° degrees to the ploughing, Tractor speed = 8.0 km/h.

From Table 5, for movement at an angle of 30° degrees to ploughing, it was found that the developed accelerations α_w = m/s^2 of the vibrations in the three directions X_{max}, Y_{max}, Z_{max}, are at high levels >0.5 m/s^2. Therefore, the allowable working hours must be less than 8 hours per day, specifically 2:05 hours. The maximum value is observed in the Z direction, α_w = 1.364 m/s^2, and the value of the daily vibration dose (DVD) in the Y direction is A(8) = 0.990 m/s^2.

Table 5

Values of the daily vibration dose (DDI) and the allowable working hours of agricultural tractor operators

Vibration Axis	Max mean values	Frequencies	DDI values A(8)	Allowed working hours	Vibrations comparison	Vibration change percentage
	[α_w = m/s^2]	[Hz]	[m/s^2]	[h]		[%]
X	0.583	2.81	0.707	—	Y→X	40.2
Y	0.817	2.81	**0.990**	**2:05**	Z→Y	34.6
Z	**1.10**	2.19	0.953	—	Z→X	88.7

DISCUSSION

The threshold values that trigger action for daily vibration exposures are 1.15 m/s^2 for A(8) and 21 m/s^1.75 for VDV. Exceeding these levels of whole-body vibrations can pose risks to health and affect the operator's ability to operate the tractor (*Gialamas et al., 2007; Gialamas et al., 2009; Gravalos et al., 2009*). It is commonly reported that these vibrations cause or exacerbate injuries to the lower back and spine. Risks are highest when accelerations are high and when the duration of exposure is long. Additionally, the frequency of the vibrations plays a significant role, as they can cause coordination issues with various body organs. Vibrations from agricultural machineries, particularly tractors, are known for their potential to induce fatigue and various other health issues in operators.

In the context of seedbed preparation using tractors, the utilization of tractors equipped with a suspension system for the operator's cabin and a seat with an adjustable vibration range is essential. This technological feature is instrumental in enhancing operator comfort and minimizing the potential health risks associated with prolonged exposure to vibrations during agricultural tasks.

The results in the tables above reveal distinct patterns in vibration levels during different tractor operations. Specifically, during disc harrowing when the tractor moved parallel to the ploughing direction, the recorded vibrations were at their lowest levels. This observation suggests that, under these circumstances, there is the potential to extend the permitted working hours beyond the standard 8 hours per day. This insight is crucial for operational planning, allowing for more flexible scheduling and increased efficiency in seedbed preparation.

Conversely, when disc harrowing occurred with the equipment moving vertically or at an angle of 30 degrees with the ploughing direction, the recorded vibrations were at their highest levels. This finding implies that, under such conditions, it is advisable to limit the permitted working hours to less than 8 hours per day. This precautionary measure is essential to prevent operator fatigue and minimize the risk of health issues associated with prolonged exposure to elevated vibration levels.

Considering the overall well-being of tractor operators, it is recommended that all modern tractors be equipped with shock-absorbing systems. These systems play a crucial role in preventing or reducing vibrations transmitted to the operator's seat and, consequently, minimize the impact on the body of the tractor operator. The implementation of shock-absorbing systems aligns with a proactive approach to occupational health and safety in agriculture. Operators of off-road machinery should be informed about possible adjustments, such as seat adjustments, to minimize the intensity of vibrations as much as possible.

CONCLUSIONS

This study presents an evaluation of the seat vibrations generated when operators work with agricultural tractors and off-road machinery. The study showed that the highest levels of vibration occurred during disc harrowing operation, particularly when the disc harrow moved vertically or at an angle of 30° to the ploughing direction. The choice of tractors with advanced features, strategic scheduling based on vibration levels during specific operations, and the integration of shock-absorbing systems are integral components in fostering a safer and more productive working environment for tractor operators engaged in seedbed preparation.

REFERENCES

[1] Adam, S.A., Abdul Jalil, N.A., Md. Rezali, K.A., & Ng, Y.G. (2020). The effect of posture and vibration magnitude on the vertical vibration transmissibility of tractor suspension system. *International Journal of Industrial Ergonomics*. 80:103014. https://doi.org/10.1016/j.ergon.2020.103014

[2] Amari, M, Caruel, E, Donati, PJE. (2015). Inter-individual postural variability in seated drivers exposed to whole-body vibration. Ergonomics. 58(7):1162–1174. doi:10.1080/00140139.2014.968633

[3] Bhuiyan, M.H.U., Fard, M. & Robinson, S.R. (2022). Effects of whole-body vibration on driver drowsiness: a review. *Journal of Safety Research*, 81:175–189. https://doi.org/10.1016/j.jsr.2022.02.009

[4] Biriș S.Şt., Constantin A-M., Anghelache D., Găgeanu I., Cujbescu D., Nenciu F., Voicea I., Matei Gh., Popa L.D., Duțu M.F., Ungureanu N., Żelaziński T., Perişoară L., Fodorean G. (2022). Considerations regarding the vibrations transmitted to the operator by an axial flow harvester combine, *INMATEH - Agricultural Engineering* 68 (3), pp. 747-756

[5] Brienza, D.M., Karg, P.E., & Brubaker, C.E. (1996). Seat cushion design for elderly wheelchair users based on minimization of soft tissue deformation using stiffness and pressure measurements. *IEEI Transactions on rehabilitation Engineering*. 4:320-327. doi:10.1109/86.547933

[6] Cheng, L., Wen, H., Ni, X., Zhuang, C., Zhang, W. & Huang, H.J.M. (2022). Optimization study on the comfort of human-seat coupling system in the cab of construction machinery. *Machines.* 11(1):30. doi:10.3390/machines11010030

[7] Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work [2008] OJL183/1.

[8] Dmitrieva, E., Myakishev, A. (2019). Improving the design of the tractor seat. *Traktory i Sel Hozmashiny.* 86(4):50–53. doi:10.31992/0321-4443-2019-4-50-53.

[9] EN 14253:2003+A1:2007 - Mechanical vibration - Measurement and calculation of occupational exposure to whole-body vibration with reference to health - Practical guidance

[10] E.U. Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work [2008] OJL183/1.

[11] E.U. Directive, G.E. Provisions, (2002). Directive 2002/44/EC of the European Parliament and the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (Vibration) (sixteenth individual directive within the meaning of article 16 (1) of directive 89/391/EEC), Off. J. Eur. Communities L 117. 6–7.

[12] Gialamas, Th., Gravalos, I., Kateris, D., Xyradakis, P., Tsatsarelis, K. and Gemtos, Th. (2007). Experimental determination of vibrations in the control room of agricultural tractors. Proceedings of the 5th Panhellenic Conference on Agricultural Engineering. 79-86.

[13] Gialamas T., Gravalos I., Kateris D., Xyradakis P., Tsiropoulos Z., Tsatsarelis K., Moshou D. and Gemtos Th. (2009). Vibrations in the operator's seat during plowing with different tractors. *Proceedings of the 6th Panhellenic Conference on Agricultural Engineering*.

[14] Goglia, V., Gospodaric, Z., Kosutic, S., Filipovic, D. (2003). Hand-transmitted vibration from the steering wheel to drivers of a small four-wheel drive tractor. *Appl. Ergon.* 34:45–49. doi:10.1016/s0003-6870(02)00076-5

[15] Gravalos, I., Gialamas, Th., Kateris, D., Xyradakis, P., Tsiropoulos, T., & Moshou, D. (2009). Vibration measurements and analysis of agricultural tractors operating on traditional and electronic regulator. Proceedings of XXXIII CIOSTA - CIGR V Conference on Technology and Management to Ensure Sustainable Agriculture, *Agro Systems, Forestry and Safety*. 2:1511-1515.

[16] Griffin, M. J., Howarth, H. V. C., Pitts, P. M., Fischer, S., Kaulbars, U., Donati, P. M., Brereton, P.F. (2006). Advisory committee on safety and health at work. Guide to good practice on hand-arm vibration. In Non-binding guide to good practice with a view to implementation of directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibrations). Luxembourg, European Commission, 61.

[17] Griffin, M.J. (2007). Discomfort from feeling vehicle vibration, *Veh. Syst. Dyn.* 45:679–698. https://doi.org/10.1080/00423110701422426

[18] ISO 2631-1:1997/AMD 1:2010 (2010). Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements — Amendment 1

[19] ISO 2631-1-5:1997 (1997). Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration

[20] ISO 10326-2:2022 (2022). Mechanical vibration — Laboratory method for evaluating vehicle seat vibration — Part 2: Application to railway vehicles.

[21] ISO 8041-1:2017 (2017). Human response to vibration - Measuring instrumentation - Part 1: General purpose vibration meters.

[22] Kumar, A., Mahajan, P., Mohan, D., Varghese, M. (2001). IT—information technology and the human interface: tractor vibration severity and driver health: a study from rural India. *J. Agric. Eng. Res.* 80:313–328. https://doi.org/10.1006/jaer.2001.0755

[23] Marsili, A., Ragni, L., Santoro, G., Servadio, P. & Vassalini, G. (2002). Innovative Systems to reduce Vibrations on Agricultural Tractors. Comparative Analysis of acceleration transmitted through the driving Seat. Bios. Eng., Silsoe Research Institute. 81:35- 47. https://doi.org/10.1006/bioe.2001.0003

[24] Nawayseh, N., Alchakouch, A. & Hamdan, S. (2020). Tri-axial transmissibility to the head and spine of seated human subjects exposed to fore-and-aft whole-body vibration. *Journal of Biomechanics*. 109:109927. https://doi.org/10.1016/j.jbiomech.2020.109927

[25] Rahmatalla, S., Qiao, G., DeShaw, J., Kinsler, R. (2023). Quantifying supine human discomfort in off-road whole-body vibration. *Ergonomics.* 66(4):479–491. doi:10.1080/00140139.2022.2096261.

[26] Ritzmann, R., Kramer, A., Gruber, M., Gollhofer, A. & Taube, W. (2010). EMG activity during whole body vibration: motion artifacts or stretch reflexes? *European Journal of Applied Physiology*. 110:143–151. doi:10.1007/s00421-010-1483-x

[27] Scarlett, A.J., Price, J.S. & Stayner, R.M. (2007). Whole-body vibration: evaluation of emission and exposure levels arising from agricultural tractors. *Journal of Terramechanics*. 44:65–73. https://doi.org/10.1016/j.jterra.2006.01.006

[28] Singh, A., Singh, L.P., Singh, S., Singh, H., Prakash, C. (2018). Investigation of occupational whole-body vibration exposure among Indian tractor drivers. *Int. J. Hum. Factors Ergon*. 5: 151–165. https://doi.org/10.1504/IJHFE.2018.092240

[29] Singh, A., Nawayseh, N., Singh, L.P., Singh, S. & Singh, H. (2018). Whole body vibration exposure during rotary soil tillage operation: the relative importance of tractor velocity, draft and soil tillage depth. *IJAME.* 15(4):5927–5940. doi:10.15282/ijame.15.4.2018.15.0452.

[30] Singh, A., Nawayseh, N., Singh, L.P., Singh, S., Singh, H. (2019). Investigation of compressive stress on lumbar spine due to whole body vibration exposure in rotary tillage operation. *IJAME.* 16(2):6684–6696. doi:10.15282/ijame.16.2.2019.16.0503.

[31] Singh, A., Samuel, S., Singh, H., Kumar, Y. & Prakash, C. (2021). Evaluation and analysis of whole-body vibration exposure during soil tillage operation. *Safety.* 7:61. https://doi.org/10.3390/safety7030061

[32] Sorainen, E., Penttinen, J., Kallio, M., Rytkonen, E., Taattola, K. (1998). Whole-body vibration of tractor drivers during harrowing. *Am. Ind. Hyg. Assoc. J.* 59:642–644. https://doi.org/10.1080/15428119891010820

[33] Village, J., Trask, C., Chow, Y., Morrison, J.B., Koehoorn, M., Teschke, K. (2012). Assessing whole body vibration exposure for use in epidemiological studies of back injuries: measurements, observations and self-reports. *Ergonomics.* 55:415–424. https://doi.org/10.1080/00140139.2011.643243

[34] Vlăduţ V., Biriş S.Şt., Bungescu T., Herişanu N. (2013). The influence of vibrations on the operator in the grain harvesters, *Applied Mechanics and Materials*, Vol. 430, pp 290-296, Trans Tech Publications, doi: 10.4028/www.scientific.net/AMM.430.290