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EVALUATION OF WHOLE-BODY VIBRATION RISK IN AGRICULTURAL TRACTOR DRIVERS

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Abstract

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During their work, agricultural tractor drivers are exposed to various negative influences, among which vibrations are especially harmful. It is about vibrations generated in engine while the tractor is working, which are then transmitted to the driver's body through the seat, the frame and the controls. Exposure to these vibrations over a longer period can lead to serious health issues. Therefore, measuring and evaluating of vibrations are critical from the aspect of developing safety measures. A measurement of vibrations in older models of IMT tractors shows that more than one-hour work with these models regularly causes a risk of intense daily vibration exposure, with the values much higher than those allowed by law. In these cases, the employer is obliged to take safety and organizational measures to reduce the vibration values to acceptable level.

Key words: whole body vibration, daily vibration exposure, agricultural tractor

Introduction

During their everyday activities, agricultural machinery operators are exposed to many negative influences that have complex and harmful impact on the man. Beside the physical strains, precipitation, unfavorable microclimate, various pollutions (dust, crop protection chemicals), high or low temperatures, noise and ergonomically inappropriate controls, vibrations are also a significant harmful factor.

They occur during psychophysical strains and are harmful for the whole body (whole-body vibration WBV). These vibrations especially affect the drivers of heavy agricultural tractors where they are transmitted through the seat, the frame and the controls to the whole body of a driver.

In comparison to obvious improvements in other performances of agricultural tractors (power, transmission, speed, high-tech controls), the protection of drivers from vibrations is unsatisfactory. The tractor chassis does not include suspension, and the tires, which are relatively flexible, are virtually only suspension that absorbs the vibrations (Deboli et al., 2008). This is why the tractor drivers are subject to relatively high-level vibrations.

Although the correlation between vibrations in heavy vehicles and some occupational illnesses was observed in the sixties in the last century, it became more obvious in the last twenty years. This is when the occupational medicine started to study a correlation between short-term and long-term periods of exposure to vibrations and some illnesses. However, the legal framework of European Union covered these issues only in 2002, when the Directive 2002/44/EC (2002) regulated legally prevention measures that tackle operators' exposure to vibrations.

It is certain now that short-term exposure to vibrations can cause annoying sensations within the human body, pain in abdomen and chest, breathing difficulties, nausea, loss of balance and worsen performance in precise controlling, while long-term exposure can lead to disorders in psychomotoric, physiological and psychic skills of a driver and cause serious health issues, especially with the spine.

Measurements of vibration levels at the seats of various tractor models have shown that the risk to the tractor drivers' health exists, even in case of drivers who are exposed to vibrations only one hour a day, while the risk is probable for all others with longer periods of exposure. Health disorders tend to show gradually, usually after two to seven years at the workplaces where operators are exposed to these vibrations (Prokeš et al., 2012).

All this is why it is essential to perform precise vibration measuring, evaluate them and assess real risk to the operators' health. Based on this data it is possible to develop safety systems that can reduce the vibration levels.

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This paper offers evaluation of exposure to vibrations levels of the whole body for drivers of some older tractor models of Serbian manufacturer IMT Belgrade (IMT 533, IMT 539, IMT 558 and IMT 560). The measuring was carried out in Vojvodina (Republic of Serbia) from 2009 to 2011 (Prokeš et al., 2012) during their everyday activities. Based on the values an evaluating of drivers' daily exposure to vibrations was carried out (with the use of a HSE software - whole body vibration calculator) (http://www.hse.gov.uk/vibration/wbv/calculator.htm), as well as an evaluating of the risk to drivers' safety at their workplaces.

Influences That Cause Vibration in Tractors

While the tractor is moving in working conditions, the whole of its framework and aggregates are exposed to complex oscillatory processes, which are caused by the driving aggregate-the engine, and are in interaction with the unevenness of the ground's surface. The factors that induce vibrations in tractors depend directly on forces and torques that generate in the engine during its work, on the way the engine is built in, on the way vibrations are spread from the engine, through the transmission over to the operator's seat.

Some researches (Adolfson, 2012) show that, except for the even asphalt, all other terrains that tractors move across have an enormous impact on vibration level. The type of tires (radial or diagonal), lateral stiffness of the tire and the pressure in tires should also be taken into consideration (Scarlett, 2005). The tires as flexible or absorbing parts of a tractor do not provide a driver an adequate protection from vibration and concussions.

In an attempt to provide optimal working conditions, the seat is probably the key factor for protection of a driver from vibrations. Together with its suspension, it must absorb vibrations and provide a driver with optimal comfort. Manufacturers all over the world have developed appropriate seats in order to provide best possible ergonomic effects.

Another important factor that gives rise to vibration level is the speed of a tractor. Some measurements have shown that at the same tillage depth, vibration level along all three axes is increased by even 40% if the speed is increased by 3 km/h only. Tractor speeds over 15 km/h require special attention and effort in order to reduce the driver's exposure to vibrations (Cvetković, and Praščević, 2005; Oude Vrielink**,** 2012).

It is hard to eliminate many factors that generate vibrations, which are through flexible, and semi-flexible joints and fasteners transmitted to the driver's seat, but it is certainly possible to reduce vibration levels with various designs. Well-known world tractor manufacturers (Class, Fendt, CAT, Case, John Deere, New Holland, JCB, Massey Fergusson…) are dedicated to the solving of these problems and have obviously improved drivers' safety and comfort in all aspects (Petrovich et al., 2005). That is why the effect of vibrations in new tractor models has been either almost eliminated or reduced way bellows the values determined by law. However, this cannot be claimed when older tractor models are considered, in case of which ergonomic aspect was not observed. Therefore, in these cases, negative vibration effects are more evident. This claim is more significant given the fact that currently 25 million tractors worldwide are 20 and more years old. Average life of 4 million tractors in the USA is more than 27 years.

At the end of the list, but at the top among the factors causing vibrations is the functioning of an operator i.e. his experience and skills. Inexperienced operators without adequate professional skills cannot recognize important factors that can increase vibration level manifold. Therefore, professional and constant training of tractor drivers and operators is crucial for reducing or complete eliminating of vibration impact.

Negative Effects of Vibrations on Tractor Drivers' Health

Human body represents a complex mechanical system consisting of many linear and non-linear elements with significant individual differences. Frequencies of vertical oscillations of some human body parts can be assumed with appropriate approximations, e.g. : head≈25 Hz, shoulders≈ 4-5 Hz, chest ≈60 Hz, spine ≈10-12 Hz, abdomen ≈4-8 Hz, hips ≈50-200 Hz, elbows ≈16-30 Hz, eye socket ≈30-80 Hz, etc. (Directive 2002/44/EC).

Resonance occurs when the forced vibrations frequency of a tractor matches the natural frequency of some driver's organ tissue. In those cases, even vibrations with relatively small amplitude can lead to significant dislocations in internal organs in the body. The spectrum of tractor vibrations' frequencies is diverse and ranges from very low 1-50 Hz (vibrations of the cab, steering wheel, axial vibrations of the tractor, wheel resonance etc.), medium frequencies 100-1000 Hz (vibrations of the transmission, exhaust system, mechanical and gasodynamic flows in the intake and discharge section etc.) and high frequencies 1000-5000 Hz (vibrations of the engine generated by the combustion, mechanical noise etc.) (Directive 2002/44/EC).

Data show that the 10-30 Hz vibrations can be felt throughout the whole body, i.e. up to 40 Hz vibrations predominantly in the head or the jaws and from 50-70 Hz vibrations only in the feet (ISO 5008:2002).

The group of all disorders and changes that occur under the influence of vibrations comprises a complex known as ''vibration sickness''. By its repetition, vibration sickness is the second among occupational illnesses, right after pneumoconiosis. Acute vibration sickness does not exist. Vibration sickness is an occupational illness, because those unemployed are not affected by it not even in the long-term periods.

The origin and the evolution of the illness are not fully understood. It is the combination of negative effects on nerves and their endings that spread to complete nervous and autonomic nervous system. The negative influences affect cardiovascular, musculoaponeurotic and skeletal system, sense of sight, heart, stomach, metabolism etc. On one hand, many disorders accompanying this illness depend on the physical features of vibrations (frequency, amplitude, speed and acceleration), on the direction of vibration spreading (vertical, horizontal, rotator), on the points of direct contact and transfer through the tissue (local and general), and on the other hand they depend on individual body features. The combination of vibrations and other occupational detriments additionally impedes the study of harmful effects of vibrations as an exclusive reason of this illness (Deboli et al., 2008).

At the beginning, patients complain about frequent and persistent headache, vertigo, fatigue, irritations and sleeping disorders. If one is exposed further to vibrations continually, the illness will include additional damages of balance centers and brain as well. The brain damage is accompanied by weakness, chronicle exhaustion, constant drowsiness, weight loss, lower blood pressure, and, additionally, some other symptoms can be seen: disorders in temperature regulation (rarely lower, more often higher temperature), in metabolism, disorders in endocrine system etc. (Deboli et al., 2008).

The changes in bones are the result of mechanical influences of vibrations that cause traumatic damages. Some studies (http://www.hse.gov.uk/vibration/wbv/calculator.htm) show a direct correlation between whole body vibrations and pain in lower parts of the spine, but also in neck and shoulders. Vibrations cause the deterioration of muscle tissue and it's mass as well as changes in tendons, with possible tendon tearing. So called ''postponed'' changes caused by vibrations are likely to occur, such as dietary, myocardial, gastric acid secretion, endocrinal, metabolic disorders etc.

Evaluating of the Whole Body Vibration Levels

Multiplied vibration levels that occur in a complex system such as tractor are transmitted to the operator in three basic ways (Petrovich et al., 2005):

- through the seat, when whole body vibration of the operator is induced
- through manual controls and the steering wheel, when vibrations in upper limbs of the operator are induced
- through the supports and the floor of the cab as well as foot controls, when mostly local vibrations in lower limbs of the operator are induced.

The direct measuring of the force that generates vibrations, which would be most desirable, is impossible. Because of that, during analysis, measuring of the system response (the consequence) to the force is carried out, the response being, in fact, the vibrations. Vibrations that are transmitted to the operator through the seat can be defined, in the domain of frequency, in the form of displacement, velocity and acceleration. If measuring that is carried out does not require measuring of a separate parameter, (because of some requirement of some standard for example), usual procedure includes choosing a parameter with the flattest response within the observed range.

Previous studies offer different indicators of the load upon the operator, and when the agricultural tractor operators are considered the most frequent standards are determined by ISO 2631-1:1997 and ISO 5008:2002, depending on the level of vertical accelerations, their frequency and the period of exposure to those accelerations. In measuring and evaluating the impact of vibrations on operators, relevant standards define acceleration as a measurement and evaluation parameter corrected with frequency-weighting function.

Evaluating of vibration impacts assumes defining three orthogonal measuring directions. For whole body vibrations, a longitudinal direction is marked as z-direction (vertical). Lateral directions are marked x and y, where x-direction (afterward) indicates forward-backward motions, and y-direction (sideward) indicates leftward-rightward motions (Figure 1).

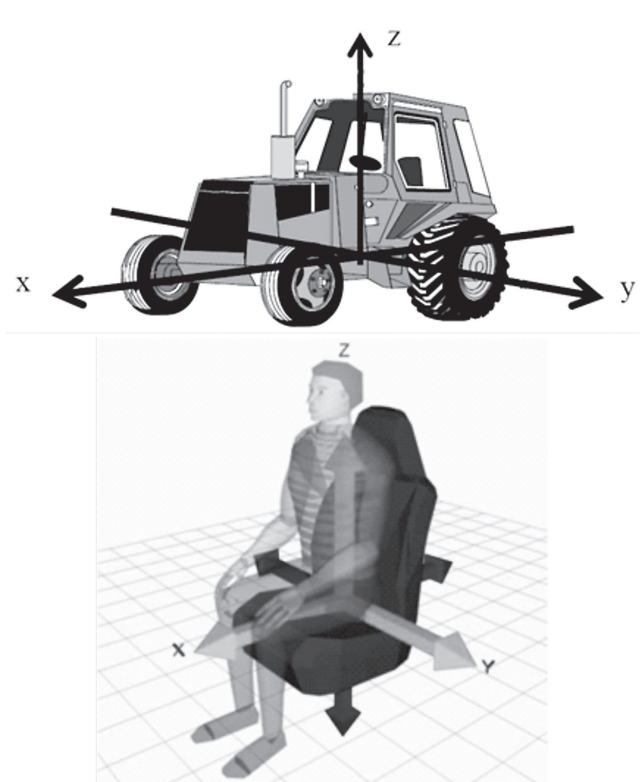

Fig. 1. Defining of orthogonal measuring directions on the tractor and the operator

Health risk because of exposure to vibrations is not equal at all frequencies. One type of a measuring filter is used for 4 to 8 Hz whole body vibrations in z-direction in tractors or on platforms and the other is for measuring 1-2 Hz vibrations in x and y directions.

Measuring of acceleration was carried out in such way that a tractor operator was sitting on his seat with an accelerometer, performing his everyday activities, driving at different speeds, on different surfaces. As a measuring device a Brüel & Kjær type 4447 human vibration analyzer was used, with a type 4524-B acceleratometer built in a Seat Pad type 4515-B-002.

Because it was needed to compare the measurement results, it was required that the working parameters for all drivers were the same.

The level of vibrations expressed as r.m.s. or effective value (root-mean-square) is equal to average acceleration, measured at the seat over the period of time during which the operator performing his task was sitting. Equivalent value of acceleration (Aeq) is a constant value of acceleration that has the energy value over some period of time T equal to the effective value of acceleration. The level of exposure depends on both vibration level and period of exposure to vibrations.

The measuring was carried out in real working conditions for four different IMT tractor models: IMT 533, IMT 539, IMT 558 and IMT 560. All models were old, with average life of more than 15 years. Some basic features of these models are shown in Table 1.

The length of activities and consequently the period of exposure to vibrations were different and were compatible with the drivers' activities scheduled for the day of measurement (Table 2)

Results Evaluation Determining of the Daily Level of Exposure

After measuring, the results are evaluated. According to 2002/44/EC Directive, the estimation of vibration level is carried out by two methods:

- Determining of the level of daily exposure, A(8) – continuous equivalent acceleration, considering 8-hour working time
- Vibration dose value (VDV), which represents cumulative dose

In case of daily exposure to vibrations that are transmitted to whole body, exposure limit value (ELV) - which must not be exceeded in professional conditions and should be 1.15

Table 1
Features of IMT tractors

Model	Power	Engine type	Weight	Max. speed
IMT 533	35KS	IMO 33/T 4 stroke diesel	1440kg	22.8km/h
IMT 539	39KS	M33/T-LP 4 stroke diesel	1440kg	22.8km/h
IMT 558	60KS	M34/T 4 stroke diesel	2040kg	27km/h
IMT 560	60KS	M34/T 4 stroke diesel	2150kg	17.8km/h

Table 2
Equivalent value of acceleration Aeq (m/s^2) in three orthogonal directions

IMT 533 – period of exposure 1h		
a_{wx} (x-axis)	a_{wy} (y-axis)	a_{wz} (z-axis)
0.23	0.17	0.55
IMT 539 - period of exposure 8h		
a_{wx} (x-axis)	a_{wy} (y-axis)	a_{wz} (z-axis)
6.01	7.25	5.42
IMT 558 - period of exposure 2h		
a_{wx} (x-axis)	a_{wy} (y-axis)	a_{wz} (z-axis)
3.44	2.42	3.85
IMT 560 - period of exposure 7h		
a_{wx} (x-axis)	a_{wy} (y-axis)	a_{wz} (z-axis)
1.95	1.58	4.00

m/s^2 - was brought up, as well as daily exposure action value (EAV) which should be 0.5 m/s^2 in case of whose higher values employers are obliged to control risks deriving from vibrations. Local legal regulations can have more restrictive demands. In Republic of Serbia, the national directive on vibrations incorporated 2002/44/EC Directive (Table 3).

The levels of daily exposures in three axes are calculated as follows:

$A_x(8)=1.4a_{wx}\,(T_{exp} / T_0)^{1/2}$

$A_y(8)=1.4a_{wy}\,(T_{exp} / T_0)^{1/2}$

$A_z(8)=a_{wz}\,(T_{exp} / T_0)^{1/2}$-

where: T_{exp} the length of daily exposure to vibrations; T_0 referent 8 working hours exposure.

The highest value of $A_x(8)$, $A_y(8)$ and $A_z(8)$ represents the level of daily exposure to vibrations.

In order to calculate the values some software can be used, e.g. HSE, whole body vibration calculator (Figure 2). Comparing calculated and legally allowed values, the software displays one of three colors: green (negligible risk), yellow (medium risk) and red (unacceptable risk).

The software also calculates, beside the daily exposure, the time needed to reach critical values of EAV and ELV

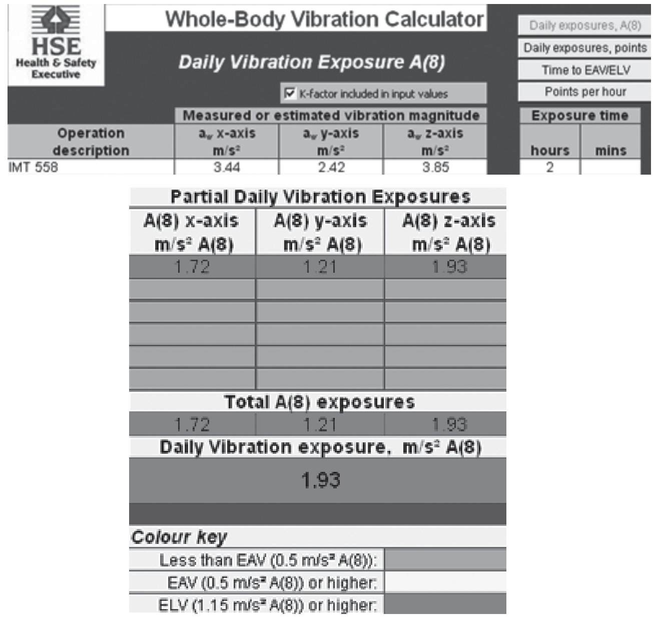

Fig. 2. HSE whole body vibration calculator-daily vibration exposure

Results Analysis

Obtained results of daily exposure show that in performing everyday activities tractor drivers face the health safety risk due to vibrations spreading throughout the whole body. During the short-term work (about 1 hour), acceleration and daily exposure A(8) values in tractors with lower power (IMT 533) were almost negligible and harmless. In tractors with higher power (IMT 560), these values were significantly higher than daily exposure action value (EAV), but still lower than exposure limit value (ELV), which indicated moderate risk. In case of IMT 558, for two-hour work, the values of daily exposure A (8) were 1.93 m/s^2 which was significantly higher above exposure limit value (ELV) and it indicated unacceptable risk. It was calculated that a driver could drive 42 minutes maximally in order not to exceed ELV, and only 8 min until EAV.

The measurements for IMT 539 show that the engine power is not the only reason for high daily exposure levels. A long working-hour period of 8 hours resulted in extremely high daily exposure level (7.25 m/s^2). In order to reduce vibration level in this model to acceptable values, drivers should not drive it more than 2 min (until EAV), i.e. 12 min. (until ELV), which is, on the other hand, insufficient time for performing any activity. Therefore, this model becomes useful, because it generates risk to operators' health.

Generally, the highest vibration level in all models was along z axis. As for IMT 539, the highest exposure value was along y axis.

High daily exposure levels are the result of deteriorated condition of all vehicles generally. Average life of all vehicles is more than 15 years, which indicates the importance of ap-

Table 3
Daily exposure to vibrations

Model	Exposure time, hours	Partial daily vibration exposures, m/s^2			Daily vibration exposure, m/s^2 A(8)	Time to EAV, hours : min	Time to ELV, hours : min
		A(8) x-axis	A(8) y-axis	A(8) z-axis			
IMT 533	1	0.08	0.06	0.19	0.19	6:36	>24h
IMT 539	8	6.01	7.25	5.42	7.25	0:02	0:12
IMT 558	2	1.72	1.21	1.93	1.93	0:08	0:42
IMT 560	1.5	0.77	0.84	0.95	0.95	0:25	2:12

propriate maintenance. Old seats, as an important factor of driver safety, do not meet most of ergonomic requests.

The vibration values are also affected by the way activities are performed, which depends on the drivers' skills. Drivers should be aware of all sources of harm, which can endanger their safety.

As for evaluated exposure levels of IMT drivers, their employer were obliged to take some of the following steps:

- For 0.5m<A(8) >1.15 m/s^2 (IMT 560) to take measures for vibration reduction, inform workers of risks related to vibrations and enable them preventive medical checkups
- For A(8) >1.15 m/s^2 (IMT 539, IMT 558) to take measures to avoid this extreme exposure, with mandatory medical check ups for workers.

Conclusion

Agricultural tractors have been identified as a hazardous machine from the aspect of the whole body vibrations. There is a risk even for those drivers who are exposed to vibrations only one hour a day.

There are many negative medical effects resulting from drivers being exposed to vibrations. When the influence of vibrations is short-termed, the symptoms are short breathing, nausea and disturbed balance, whereas long-term influence causes disorders in psychomotoric, physiological and psychological systems.

Although well-known world manufacturers are dedicated to reducing vibrations, most of the world's tractors are 20 and more years old and do not meet basic ergonomic requests. Here, the effects of vibrations are especially evident.

This is why it is important to measure vibration levels constantly, evaluate them and determine the risk for driver's safety. Depending on the risk, organizational and technical measures for vibration reduction should be taken.

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