FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 12, N° 1, 2015, pp. 73 - 81

THE EXPERIENCE OF DRIVERS AND THE PERFORMANCE OF DRIVING AS IMPACT FACTORS OF VIBRATION LEVELS IN AGRICULTURAL TRACTORS

UDC 656.1:534:631.372

Boban Cvetanović, Dragan Cvetković, Miljan Cvetković

College of Applied Technical Sciences Niš, Republic of Serbia

Abstract. *During everyday agricultural activities, tractor drivers are exposed to harmful effects caused by various factors. Some of the negative factors are vibrations caused by driving aggregates and the implements combined with the rough soil. These oscillatory loads are transferred to the cab, through the floor and the seat to the body of the driver. In case of high level vibrations and during a long period of exposure, many health problems occur. Harmful effect of the vibrations is especially obvious in older models of improperly suspended tractors, which are equipped with simple mechanical seats. High intensities of vibrations above permitted limits were found at the seat of the driver. A quality seat, proper suspension and good tires have impact on both the intensities of vibrations and their reduction. Organizational measures such as shorter shifts and a change of drivers can only reduce the level of daily exposure, but can neither affect the intensity of vibrations nor their reduction. On the other hand, the drivers' awareness of harmful effects of vibrations, detailed trainings and drivers' experience can affect the vibration level significantly. This paper attempts to show the effect of drivers' experience on the intensities of vibrations. Driver's skills, i.e. the performance of his driving, can have considerable influence on vibration level, with the effect more obvious in older tractor models than in new ones. The measurement results with three different drivers (in the same working conditions the same tractor model, type of soil and working operation) show the influence of driver's skills, i.e. driving performance, on the vibration level. A skillful driver, in almost same working conditions, can reduce vibration levels even to 20 times in comparison to an inexperienced one.*

Key words: *agricultural tractor, vibration, plowing, driver's experience, driving performance*

Received November 27, 2014 / Accepted February 27, 2015
Corresponding author: Boban Cvetanović
College of Applied Technical Sciences Niš, Republic of Serbia
E-mail: boban.cvetanovic@vtsnis.edu.rs

1. INTRODUCION

Without a doubt, agricultural tractors have contributed enormously to the efficiency of agricultural operations making them easy and, in some cases, eliminating human labor completely. On the other hand, during their everyday activities, tractor drivers are exposed to many harmful influences which have complex negative effect to the health and hinder drivers' performances. These influences come both from the tractor system (noise, inadequately designed controls) and from the working conditions (precipitation, high relative humidity, dust, agriculture chemicals, high or low temperatures etc.). One of the important negative factors is vibrations [1]. Namely, during the operations, the entire tractor construction is subject to complex oscillatory processes induced by the combined influences of rough soil and a tractor aggregate and its implements. These high levels of vibrations that arise in such a complex system, such as tractor, are transferred from the cab floor to the seat and on to the whole body of the driver.

Vibrations can have high values and unfavorable frequencies, thus imposing great risk to the driver's health. Because of combined influences of vibrations and other occupational health risks, it is not always possible to establish the correlation between the effect of vibrations and the illness of drivers. However, numerous scientific studies, bio-dynamic models and present knowledge of human body show that prolonged exposure to high-level vibrations can lead to low-back injuries, digestive system illnesses and cardio-vascular problems [2-6].

The harmful impact of vibrations is especially evident in older models of tractors which are not equipped with appropriate suspension system for shock and vibration absorption. The case of modern models, from that aspect, is better because they are equipped with improved suspension systems and seats. However, in comparison to the improvements in the categories of power, fuel consumption, velocity or electronic controls, there is still room for additional improvements in protection of drivers from vibrations.

In Serbia, there are 410 894 tractors, most of which (about 350 000) were manufactured by a Serbian manufacturer IMT - Industrija motora i traktora Beograd and all of them are more than 20 years old [7]. During the development of the tractors, from the aspect of oscillations, little attention was paid to comfort in driving in different working conditions, i.e. to tractors' capacity to reduce the negative influence of the oscillation of individual components on the driver to the least possible extent. In these tractors, shock absorption is done by tires and mostly simple mechanical seats, without additional suspension systems. Even today, this manufacturer considers optimizing of the elastic suspension system as a significant cost in production. The measurements of vibration levels at IMT tractor seats and their evaluations showed that the daily levels of exposure to vibrations were high [8].

A quality seat, suspension system and good tires affect both vibration levels and their reduction, but they are too expensive for farmers. Organizational measures such as shorter working shifts and a change of drivers can only reduce the level of daily exposure, but can affect neither the intensity of vibrations nor their reduction. On the other hand, the drivers 'awareness of vibrations' harmful effect, detailed trainings and drivers' experience can affect the vibration level significantly.

This paper is an attempt to learn how much a well-performed driving, i.e. the experience of a driver affect the level of vibrations. A skillful driver, i.e. the performance of his driving, can have considerable influence on vibration level, with the effect more obvious in older tractor models than in new ones.

2. THE METHOD OF MEASUREMENTS

For the purpose of vibration level measurements (RMS accelerations), IMT 533 and 539 tractor models were used. The models have almost the same characteristics and they are said to be the most numerous models in Serbia. All of the tractors are equipped with simple mechanical seats and have the same engine - IMR M33/T, with the power of 35 to 39 HP. The difference was in the date of manufacturing, and the measuring was performed during plowing (the depth of 25 cm), during which high vibration levels occur. The average velocity of the tractors was 5km/h. The plowing was performed with two-furrow plows, on a similar types of soil.

Fig. 1 Tractor No 1 IMT 539

Tractor No. 1, IMT 539, was manufactured in 1990, with about 1300 hours at the moment of measurement (fig. 1). The driver weighted 90 kg and was 187 cm tall and had 10-year experience in operating with the tractor whose number of hours was small.

The tractor No. 2, was also IMT 539, manufactured in 1987, and had, at the moment of measuring, 5500 hours (fig 2). The driver weighted 75 kg, and was 173 cm tall, with 30 years of experience in working with tractors.

Fig. 2 Tractor No 2 IMT 539

Tractor No 3 was IMT 533, manufactured in 1978., with over 10 000 hours at the moment of measuring. (two overhauls). The driver weighted 81 kg and was 175 cm tall with the longest experience of all three drivers in driving tractors.

Fig. 3 Tractor No 3 - IMT 533

Table 1 Relevant data

Driver	Tractor model	Manufactured in	Driver's experience (years)	Driver's age
1	IMT 539	1990.	10	45
2	IMT 539	1987.	30	63
3	IMT 533	1978.	35	60

For the measuring of vibration level a human vibration measuring device was used. The model was Brüel & Kjær Type 4447, with an accelerometer enclosed in a rubber pad, placed on the driver's seat (fig. 4)

Each measuring lasted at least 20 min, when the device displayed (except RMS acceleration values along all three axes) the level of daily exposure of drivers to vibrations A(8) for the reference time of 8 working hours. Obtained values were compared to the highest permitted values specified in EU Directive 2002/44/EC [9] and in Serbia specified in Serbian Rulebook of Safety precautions during exposure to vibrations [10].

Fig. 4 Human Vibration Analyzer Type 4447

In case of daily exposure to whole body vibrations, two values were suggested: an exposure limit value (ELV) which in professional working conditions must not be exceeded and is 1,15m/s^2 and exposure action value (EAV), above which employers must control health risks deriving from vibrations and which is 0,5m/s^2.

3. RESULTS

During the measurements, RMS values for all three axes were obtained. The highest values in all three cases were along X-axis, i.e. along the direction of tractors' motions (Table 2).

Table 2 Intensities of RMS accelerations

Driver	Tractor model	max RMS acceleration [m/s^2]
1	IMT 539	8.942
2	IMT 539	4.494
3	IMT 533	0.824

In order to compare legally permitted values (Table 3) with these obtained values, the daily level of exposure can be calculated for 8-hour reference time A(8) which is usual working shift. Obtained values show what the daily value of exposure of the driver would have been, if he had spent 8 hours of his shift operating with the tractor, without any interruptions, with the values of acceleration measured. The instrument itself calculates daily level of exposure for 1 hour- A(1), 4 hours – A(4) and 8 hours of continuous work - A(8), which makes possible to analyze values in case the driver had spent half the shift (or 1 hour only) driving, and the rest of the time performing some other activities not related to driving or having breaks during the shift.

In order to calculate daily values of exposure for different periods of exposure, an appropriate free software for calculating daily values of exposure A(8) for given periods is available.

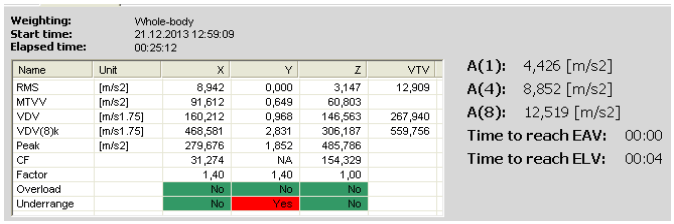
Table 3 Daily levels of exposure

Driver	Tractor model	Daily level of exposure A(8) m/s²	Time to EAV [h:min]	Time to ELV [h:min]
1	IMT 539	12.519	00:00	00:04
2	IMT 539	6.292	00:03	00:16
3	IMT 533	1.153	01:30	07:56

4. DISCUSSION

The technical features of tractors, during measuring, were almost identical, with IMT 539 a bit better than IMT 533 in terms of power and date of production. The daily levels of exposure of the drivers to vibrations were above the highest permitted values in all three cases. Mostly, this was due to life of the tractors and the fact that the design and construction of the tractors dated 40 years ago, a period when ergonomic requests were not observed. Outdated suspension and seats cannot absorb vibrations generated during the work of old diesel engines that are parts these tractors, if they are combined with the rough soil. However, the expectations of new models to reduce the vibration levels have not been fulfilled, which indicates that some other factors, such as the quality of driving, may affect the vibration level at the driver's seat significantly.

The measuring of vibrations at the seat of the first tractor lasted 25 min, and the calculation for 8-hour reference time gave extremely high daily level of exposure A(8)=12,519m/s^2, which is almost 10 times higher than legally permitted value (Fig. 5). A driver must not operate this tractor more than 4 min. This tractor was the best in terms of technical conditions, with the least number of hours.



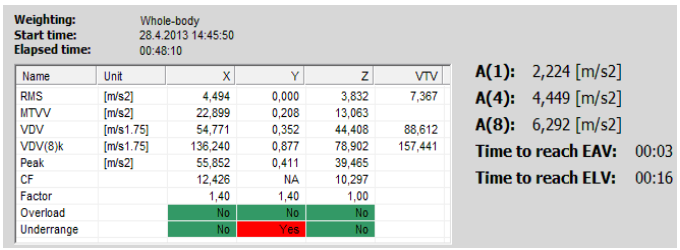
Weighting: Whole-body
Start time: 21.12.2013 12:59:09
Elapsed time: 00:25:12

Name	Unit	X	Y	Z	VTV
RMS	[m/s2]	8,942	0,000	3,147	12,909
MTVV	[m/s2]	91,612	0,649	60,803	
VDV	[m/s1.75]	160,212	0,968	146,563	267,940
VDV(8)k	[m/s1.75]	468,581	2,831	306,187	559,756
Peak	[m/s2]	279,676	1,852	485,786	
CF		31,274	NA	154,329	
Factor		1,40	1,40	1,00	
Overload		No	No	No	
Underrange		No	Yes	No	

A(1): 4,426 [m/s2]
A(4): 8,852 [m/s2]
A(8): 12,519 [m/s2]
Time to reach EAV: 00:00
Time to reach ELV: 00:04

Fig. 5 Values of acceleration and levels of daily exposure for tractor No 1. IMT 539

The measuring of vibrations at the seat of the second tractor IMT 539 lasted 48 min, and obtained daily level of exposure A(8)=6,292 m/s^2 was more than 5 times higher than legally permitted value. A driver could operate this tractor for only 16 min., when the permitted value of exposure would be reached (Fig.6).



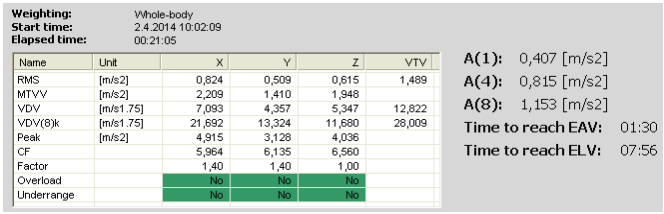
Weighting: Whole-body
Start time: 28.4.2013 14:45:50
Elapsed time: 00:48:10

Name	Unit	X	Y	Z	VTV
RMS	[m/s2]	4,494	0,000	3,832	7,367
MTVV	[m/s2]	22,899	0,208	13,063	
VDV	[m/s1.75]	54,771	0,352	44,408	88,612
VDV(8)k	[m/s1.75]	136,240	0,877	78,902	157,441
Peak	[m/s2]	55,852	0,411	39,465	
CF		12,426	NA	10,297	
Factor		1,40	1,40	1,00	
Overload		No	No	No	
Underrange		No	Yes	No	

A(1): 2,224 [m/s2]
A(4): 4,449 [m/s2]
A(8): 6,292 [m/s2]
Time to reach EAV: 00:03
Time to reach ELV: 00:16

Fig. 6 Values of acceleration and levels of daily exposure for tractor No 2. IMT 539

The model of IMT 533 was, in terms of technical conditions, the worst in comparison to other two tractors, but the level of daily exposure was nearly at the limit value. A driver could operate this tractor almost full 8-hour working shift. It seems that this driver performed the plowing better and faster, although this tractor moved at the same velocity like two other tractors.



Weighting: Whole-body
Start time: 2.4.2014 10:02:09
Elapsed time: 00:21:05

Name	Unit	X	Y	Z	VTV
RMS	[m/s2]	0,824	0,509	0,615	1,489
MTVV	[m/s2]	2,209	1,410	1,948	
VDV	[m/s1.75]	7,093	4,357	5,347	12,822
VDV(8)k	[m/s1.75]	21,692	13,324	11,680	28,009
Peak	[m/s2]	4,915	3,128	4,036	
CF		5,964	6,135	6,560	
Factor		1,40	1,40	1,00	
Overload		No	No	No	
Underrange		No	No	No	

A(1): 0,407 [m/s2]
A(4): 0,815 [m/s2]
A(8): 1,153 [m/s2]
Time to reach EAV: 01:30
Time to reach ELV: 07:56

Fig. 7 Values of acceleration and levels of daily exposure for tractor No 3. IMT 533

5. CONCLUSION

The measurements of vibration levels in three IMT tractors (models 533 and 539) showed that while plowing with these tractors, drivers face health risks from vibrations. Although the working conditions and working modes were similar, the lowest levels of vibrations were present in the oldest tractor, IMT 533, which was operated by the most

experienced driver. On the other hand, the first tractor IMT 539 was manufactured 10 years after the third one, but was operated by a relatively inexperienced driver, so the values of daily exposure reached unacceptable figures, ten times more than legally permitted ones. It indicates the importance of experience in driving tractors, not only in terms of vibration levels, but also in terms of drivers' safety.

Without a doubt, technical measures affect the level of vibrations and their reduction. However, one should always keep in mind that the vibration levels, especially their spreading, are also affected by a driver himself. A skilled and experienced driver, who is familiar with his vehicle and aware of harm from vibrations as well, will be able to affect the vibration levels efficiently. The experience of drivers is especially obvious in driving tractors without proper shock and vibration absorption system.

REFERENCES

1. M.Bovenzi et al., An epidemiological study of low back pain in professional drivers, *Journal of Sound and Vibration* 298 (3) (2006) 514-539.
2. H.C.Boshuizen et al., Self-Reported Back Pain in Tractor Drivers Exposed to Whole-Body Vibration, *International Archives of Occupational and Environmental Health.* 62 (1990) 109-115.
3. O.O. Okunribido, M. Magnusson, M.H. Pope, Low back pain in drivers: The relative role of whole-body vibration, posture and manual materials handling, *Journal of Sound and Vibration* 298 (3) (2006) 540-555.
4. M.Bovenzi, C.T.Hulshof, An Updated Review of Epidemiologic Studies on the Relationship Between Exposure to Whole-Body Vibration and Low Back Pain, *Journal of Sound and Vibration* 215(1998) 595-611.
5. M.Futatsuka et al**.,** Whole-Body Vibration and Health Effects in the Agricultural Machinery Drivers, *Industrial Health.* 36(1998) 127-132.
6. B.Cvetanović, J.Jovanović, A review of harmful effects to the health of tractor drivers from the impact of whole body vibration, *Tractors and power machines* 18 (3) (2013) 58-65.
7. A.J.Scarlett, J.S.Price, R.M.Stayner, Whole – body vibration: Evaluation of emission and exposure levels arising from agricultural tractors, *Journal of terramechanics* 44 (2007), 65-73.
8. B.Cvetanović, D.Zlatković, Evaluation of whole-body vibration risk in agricultural tractor drivers. *Bulg. J. Agric. Sci.* 19 (2013) 1161-1166.
9. I.Hostens, K.Deprez, H.Ramon, An improved design of air suspension for seats of mobile agricultural machines, *Journal of Sound and Vibration*, 276(1–2) (2004) 141-156.
10. Agricultural list 2012 - Agriculture in the Republic of Serbia, Institute of Statistics, 2012.
11. European Parliament and the Council of the European Union: Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration), 2002.
12. Official Journal of the European Communities, OJ l 177,13
13. The Official Gazette of Republic of Serbia, No. 101/05, Rulebook of Safety precautions during exposure to vibrations, 2005.

ISKUSTVO VOZAČA I KVALITET VOŽNJE KAO UTICAJNI FAKTOR NA VELIČINU VIBRACIJA KOD TRAKTORA

Tokom obavljanja različitih poljoprivrednih aktivnosti, vozači traktora su izloženi štetnom dejstvu mnogobrojnih faktora. Jedan od štetnih uticaja su i vibracije koje nastaju kao posledica rada pogonskih agregata i priključnih mašina, u sadejstvu sa neravninama tla. Ova oscilatorna opterećenja prenose se do kabine, i dalje preko poda i sedišta, do celog tela vozača. U slučaju visokih intenziteta vibracija i pri dužem izlaganju nastaju brojna oštećenja zdravlja. Štetno dejstvo vibracija, naročito je izraženo kod traktora starije generacije, koji nemaju kvalitetno ogibljenje i uglavnom su opremljeni prostim mehaničkim sedištima. Merenjima vibracija na sedištu vozača, kod ovih traktora, uočene su visoke vrednosti vibracija, iznad zakonski dozvoljenih granica. Kvalitetno sedište,

ogibljenje i dobri pneumatici utiču kako na veličinu nastalih vibracija, tako i na njihovu redukciju. Organizacione mere kao što su skraćenje smene i zamena vozača, mogu samo da smanje dnevnu izloženost vozača, ali ne i da utiču na intenzitet vibracija, niti na njihovu redukciju. Sa druge strane, informisanje vozača o štetnom dejstvu vibracija, kvalitetna obuka i iskustvo vozača mogu, u velikoj meri, da utiču na intenzitet nastalih vibracija. Ovaj rad pokušava da ukaže na uticaj iskustva vozača na intenzitet vibracija. Kvalitet vozača, odnosno njegove vožnje, može u velikoj meri uticati na veličine nastalih vibracija, pri čemu je taj uticaj mnogo izraženiji kod starih, nego kod traktora novije generacije. Kroz rezultate merenja vibracija, sa tri različita vozača, sa istim uslovima rada (vrsta traktora, vrsta zemljišta, ista poljoprivredna operacija...), može se videti koliki uticaj ima znanje vozača tj. njegova kvalitetna vožnja na veličine vibracija koje se mere. Dobar vozač, u gotovo istim uslovima, može dovesti vrednosti vibracija do nivoa koji je, čak i dvadeset puta manji od onih koji se javljaju kod neiskusnog vozača.

Ključne reči: *poljoprivredni tractor, vibracije, oranje, iskustvo vozača, kvalitet vožnje*