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

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Abstract - *During everyday operations with tractors, drivers are exposed to harmful effects of various factors. One of the negative factors are vibrations deriving from driving aggregates and implements combined with the rough soil. These oscillatory loads are transferred to the cab, and 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 to them, many health problems occur. Harmful effect of the vibrations is especially obvious in older models of tractors which don't have proper suspension, but are equipped with simple mechanical seats.. During measuring of vibrations at the seat of the driver, high intensities of vibrations were found, above permitted limits. A quality seat and suspension as well as good tires affect both the intensities of vibrations and their reduction. Organizational measures such as shorter working shifts and a change of drivers can only reduce the level of daily exposure, but can't 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 work presents an attempt to show the effect of drivers' experience on the intensities 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. The measurement results, with three different drivers (in the same working conditions: the same tractor model, type of soil and working operation), show how influential for the vibration level the driver's skills i.e. well-performed driving are. A skillful driver, in almost same working conditions, can reduce vibration levels even 20 times in comparison to an inexperienced one.*

Key words: *agriculture tractor, vibration, plowing, driver's experience, the performance of driving*

1. INTRODUCTION

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 are 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 like the 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 unfavourable frequencies 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 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't 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 to 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 more 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, that was because of the life of the tractors and the fact that the design and construction of the tractors dated 40 years ago, 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, combined with the rough soil. However, the expectations of new models to reduce the vibration levels haven't 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 mustn't operate this tractor more than 4 min. This tractor was the best in terms of technical conditions, with the least number of hours.

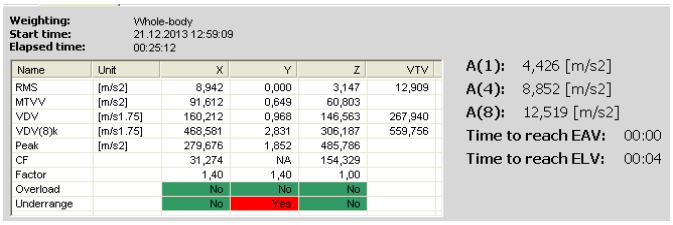


Fig 5. *Values of acceleration and levels of daily exposure for tractor No 1. IMT 539*

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).

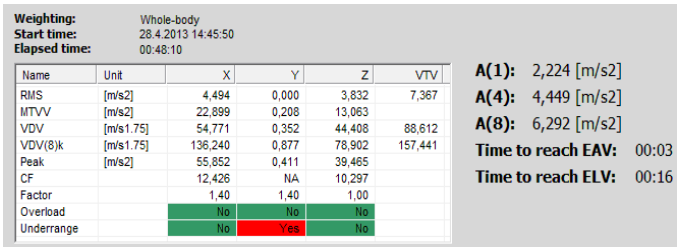
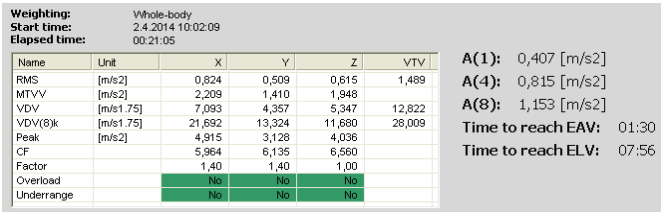


Fig 6. *Values of acceleration and levels of daily exposure for tractor No 2. IMT 539*

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.



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	

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 i 539) showed that when 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 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, and especially their spreading, is 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.

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