Effect of the Suspension on Whole Body Vibration: Comparison of High Power Agricultural Tractors

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The reduction of the whole body vibration (wbv) in agricultural tractor drivers should be done by the suspension of the driver's seat, of the tractor's cab or of the front and rear axles. The seat is a vital part of a tractor and is designed to provide comfort for driver and reduce high vibration levels that are harmful for the drivers. Regardless of the fact that the seat has active or passive suspension, it cannot fully protect the driver, so there should be an additional suspension system between the source of vibrations and the seat. Most of older tractor models, except in the seat and tires, don't have other efficiency suspension system, whereas the manufacturers of modern models constantly develop new solutions and suspension systems.

This paper gives comparative analysis of vibration levels in tractors of new generations, with different suspension systems: suspended front axle & suspended cabin tractor and fully suspended (front & rear axles) tractor. The measurement of vibrations was carried out in real "on-farm" conditions, during ploughing and cultivating.

On the basis of vibration levels at the driver's seat (for all three coordinates, x, y, z) and the period of exposure, the daily exposure of the driver will be calculated and whether the values are within the legal limits will be determined.

Keywords: High power, agriculture tractor, Whole body vibration

1. INTRODUCTION

During their everyday activities, agricultural tractor operators are exposed to many negative influences that have complex and harmful impact on the man. These influences come both from the tractor system (noise, vibrations, exhaust gases, bad ergonomy...) and from the working conditions (precipitation, high relative humidity, dust, agriculture chemicals, high or low temperatures etc.). One of the most 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. 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].

Some studies show that about 9% of all world's tractors, during 8-hour working time, are exposed to vibrations above exposure limit value (ELV), while in case of longer working time that percentage increases to 27%. As many as 95% of all tractor drivers during 8-hour working time are exposed to levels above exposure action value (EAV) [4].

In the reduction of the vibrations, the suspension of the tractor in the combination with the driver's seat plays the most important part. In older generations of tractors, the vibration reduction was done with the tires, the driver's seat and a simple suspension on the front axle, because the tractor manufacturers considered good quality suspension too difficult and too expensive.

Today, there are three types of tractor construction when it comes to suspensions [3]:

- suspended cabin tractor,
- suspended front axle & suspended cabin tractor
- fully suspended (front & rear axles) tractor.

During the 1970's many tractor manufacturer (Ford, John Deere, Massey Ferguson…) were developed tractor cab suspension system, but only Renault (now Claas) in 1987 developed and offered the Hydrostable cabin suspension system with four coil-over-damper suspensions at each cabin corner. There was the first, mass-produced tractor cab suspension system and is the most numerous in use. Today every tractor manufacturer either offers some form of cab suspension system, or is in the process of developing a system to meet perceived market demand. New Holland offers a Comfort Ride system where the front of the cab is on rubber-metal mounts and the rear cab corners are suspended on coil-over-damper suspensions over the rear axle [3,5].

During the 1980's many tractor manufacturer viewed tractor axle suspension as a complex design challenge of dubious economic benefit. The majority of system provided suspension of the tractor front axle only. Provision of rear axle suspension was considerably more complex tasks. Only JCB, towards the end of the 80's, launched the Fastrac, a front and rear axle suspended chassis. Over a two decade on, with an unchanged basic design and a range comprising six models, JCB can justly claim the Fastrac to be the most successful fully suspended agricultural tractor produced to date [6] (figure 1).

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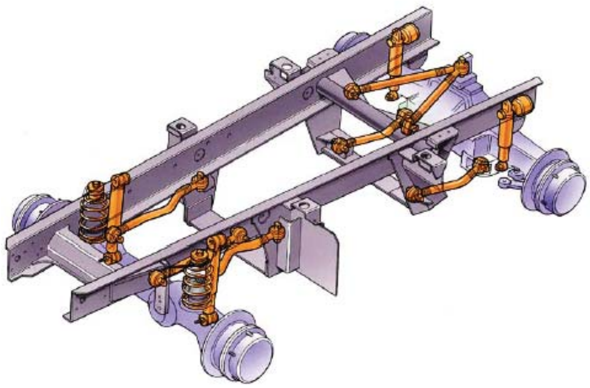

Figure 1: JCB Fastrac chassis and suspension system

Other tractor manufacturers (New Holland and John Deere) didn't develop fully suspended vehicle, but they developed optional front axle suspension and cab suspension systems which proved satisfactory on the market and can be considered a standard tractor suspension system in Europe today (figure 2)

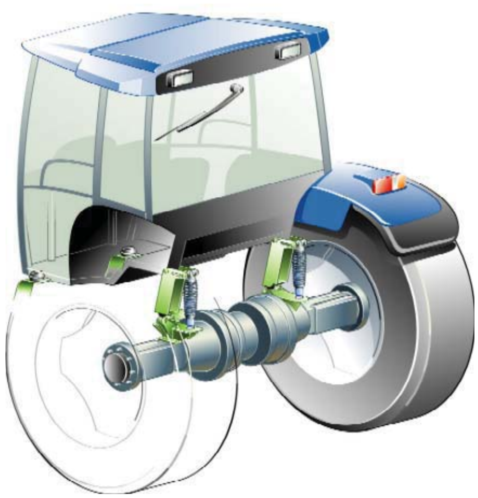

Figure 2. New Holland Series TM tractor 'Comfort Ride' cab suspension system

The system utilizes self-leveling air-over-oil (hydropneumatic) suspension elements, powered by the tractor hydraulic system and providing both springing and damping functions.

This paper will give the comparison of two suspension types of well-known manufacturers (*New Holland and JCB*) with respect to measured whole body vibration levels during various agricultural operations. An important aspect of measuring will be the estimation of driver's exposure to whole body vibration during referent eight-hour period, based on the previously measured values for shorter referent periods.

2. THE METHOD OF MEASUREMENT

The measurement of vibrations was carried out in real (on-farm) conditions, during several standard agricultural activities and two suspension types were compared:

(a) suspended front axle & cab suspended (at rear only) - New Holland TM 165 (figure 3)

Figure 3. New Holland TM 165

(b) suspended front & rear axles - JCB Fastract 3185 (figure 4)

Figure 4. JCB Fastract 3185

Some characteristics of the tractors are given in Table 1.

Table 1: Some characteristics of tractors

Tractor	Power	Engine type	Weight
New Holland TM 165	123kW (165hp)	New Holland turbocharged diesel liquid cooled	6556kg
JCB Fastract 3185	140kW (188hp)	Cummins 6BTA, intercooled turbodiesel 6-cylinder	6765kg

A summary of test tractor suspension seat specifications is given in Table 2

Table 2: Tractor suspension seat details

Tractor	Seat model	Suspension type		
		Z-axis	X-axis	Y-axis
New Holland TM 165	Sears SA 15748	Air spring (adj.) + damper (adj.)	Mech. spring (fixed) + damper (adj.)	None
JCB Fastract 3185	Grammer MSG95 A/721	Air spring (adj.) + damper (fixed)	Mech. spring (fixed) + damper (adj.)	None

"adj." = adjustable rate or pre-load: "fixed" = fixed rate: "Mech." = mechanical

The tractors performed their everyday regular agricultural activities (ploughing and cultivating) whose lengths were different, but the drivers' level of daily exposure to vibrations A(8) was measured for a referent 8-hour period.

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 [7], 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.

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. The vibration measurement was carried out at the driver seat (figure 5).

Figure 5. Tractor wbv measurement instrumentation

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. The vibration levels were measured in three orthogonal measuring directions: z-direction (vertical), x-direction (afterward) and y-direction (sideward) (figure 6).

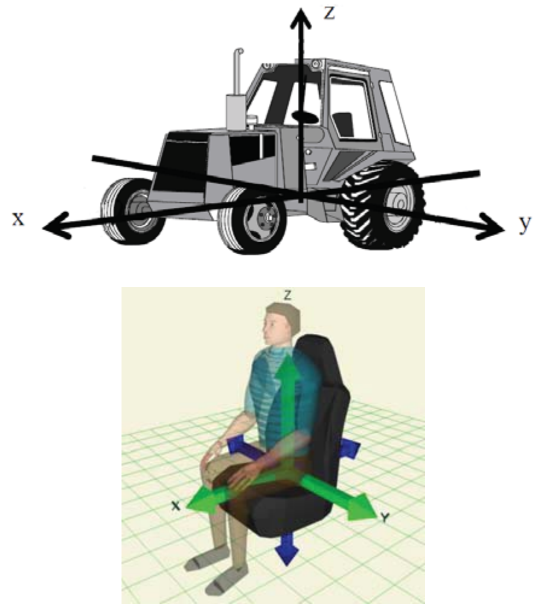

Figure 6. Defining of orthogonal measuring directions on the tractor and the operator

The level of vibrations expressed as RMS 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 obtained values were compared to maximal permitted values that are, in EU, regulated with the Directive 2002/44/EC [8]. Republic of Serbia incorporated the Directive 2002/44/EC into its legal framework. In case of daily exposure to whole body vibrations it specifies exposure limit value (ELV) of 1,15 m/s^2 which must not be exceeded in professional working conditions and exposure action value (EAV) of 0,5m/s^2, in case of which employers must control the risks coming from vibrations.

3. RESULTS

During the measurements, the RMS (root mean square) acceleration values for all three axes for New Holland were (table 3):

Table 3. RMS values for New Holland

Task	Duration [hr:min]	Average RMS (Aeq) acceleration [m/s^2]			
		X	Y	Z	Aeq
Ploughing	3.25	0.58	0.86	0.47	**0.86**
Cultivating	4.45	0.45	0.67	0.31	**0.67**

k- factor included in input values

Time history of weighted RMS seat accelerations (Y-axis) and running average of RMS acceleration (Aeq) (Y-axis) for tractor New Holland and cultivating are shown on figure 7.

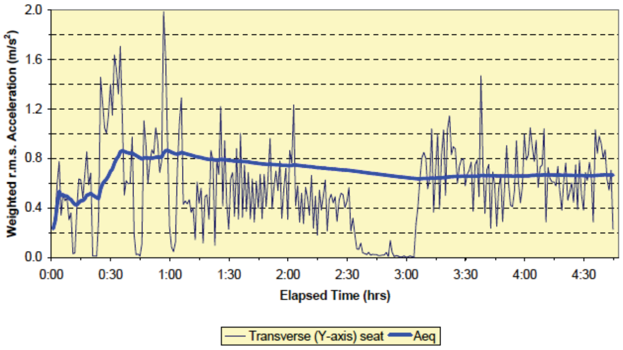

Figure 7. RMS seat accelerations (Y-axis) and Aeq (Y-axis) - New Holland (cultivating)

The RMS acceleration values for all three axes for JCB were (table 4):

Table 4. RMS values for JCB

Task	Duration [hr:min]	Average RMS (Aeq) acceleration [m/s^2]			
		X	Y	Z	Aeq
Ploughing	4.00	0.54	0.93	0.33	**0.93**
Cultivating	4.00	0.89	1.39	0.63	**1.39**

k- factor included in input values

Time history of weighted RMS seat accelerations (Y-axis) and running average of RMS acceleration (Aeq) (Y-axis) for tractor JCB and ploughing are shown on figure 8.

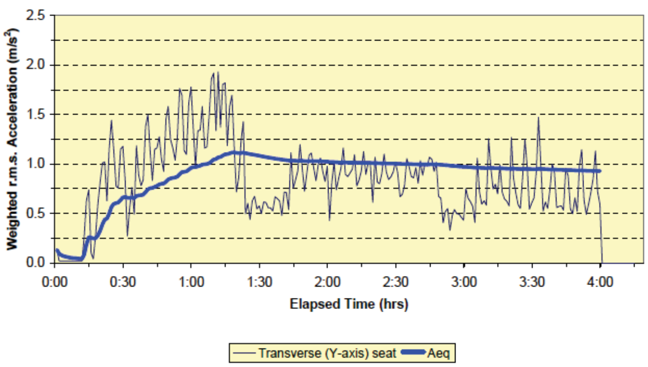

Figure 8. RMS seat accelerations (Y-axis) and Aeq (Y-axis) - JCB (ploughing)

Considering the durations of measurements it was necessary to establish daily values of exposure of the driver for 8-hour reference time A(8), which is usually the duration of one shift, in order to make comparison to legally permitted values.

The values of Aeq in Table 3. and Table 4. (bold) 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 obtained during measuring.

The values of daily exposure A(8) in Table 5. and Table 6. (bold) show what the daily value of exposure of the driver would have been, if he had spent less time than eight hours operating with the tractor (eg 3:25hr, 4:45hr or 4hr) and the rest of the time performing some other activities not related to driving or having breaks during the shift.

Table 5. Daily exposure levels - New Holland

Task	A(8) [m/s^2]	Time to EAV [hr]	Time to ELV [hr]
Ploughing	**0.55**	2.7	14.3
Cultivating	**0.52**	4.45	23.5

Table 6. Daily exposure levels – JCB

Task	A(8) [m/s^2]	Time to EAV [hr]	Time to ELV [hr]
Ploughing	**0.66**	2.3	12.22
Cultivating	**0.98**	1.04	5.46

In order to calculate daily values of exposure for different periods of exposure, appropriate free software for calculating daily values of exposure A(8) for given periods is available (figure 9).

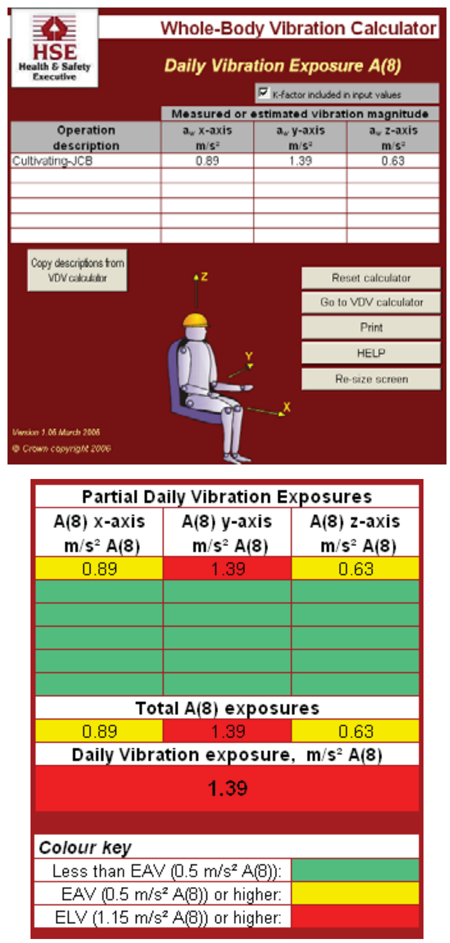

Figure 9.Wholy body vibration calculator

4. DISCUSSION

Both tractors (both suspension types) had highest vibration levels along Y axe (transverse). The reason for that is in the tractor suspension seat. Both tractors were fitted with scissor linkage – type suspension seats embodying air spring / hydraulic damper vertical (Z) suspension system and also all seats embodied limited longitudinal (X) axis mechanical spring and hydraulic damper suspension. In (Y) axis they didn’t have any suspension type.

The comparison of calculated values to permitted exposure values regulated in Directive EC 2002/44 (action value EAV=0.5m/s^2 and limit value ELV=1.15m/s^2) shows that in case of New Holland EAV was exceeded in ploughing operation while in the case of cultivation operation daily exposure is near EAV. In case of JCB tractor, EAV was exceeded for both agriculture operation.

In these measurements the type of agricultural activity didn’t have too much affect on the values of vibrations at the driver seat. However, time to EAV, in all operations, is below eight hours, which means that the drivers, in case of full working day (8 hours min.), will certainly be exposed to negative impact of whole body vibration.

5. CONCLUSION

According to calculated daily exposure levels to whole body vibration, for both tractors and for two different operations, it can be concluded that with respect to vibration reduction front axle & cab suspension system is more efficient than front & rear axles suspension system. However, it must be mentioned that vehicle whole body vibration emission levels are dependent not only upon vehicle design and the presence of vibration reduction features (e.g. suspended seats, cabs & axles), but also upon operating surface, forward speed and personal driving technique. Therefore, it cannot be simply concluded that fully suspended tractor always has higher vibration levels. To draw this conclusion, larger number of vehicles should be tested, with identical organizational and technical conditions, which is difficult to do in practice.

Also, we should know that vehicle whole body vibration emission levels are dependent not only upon vehicle design and the presence of vibration reduction features (e.g. suspended seats, cabs & axles), but also upon operating surface, forward speed and personal driving technique.

In tractors of older generations without suspension system or with primitive system, the situation with respect to driver’s exposure to whole body vibration is worrying. Even in modern tractors with developed suspension systems, the vibration levels during work are relatively high. It seems that tractor manufacturers still don’t consider protecting drivers from whole body vibration, having in mind the improvements achieved in other aspects (power, torque, transmission, electronic devices, etc.).

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