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ANALYSIS OF DRIVING SEAT VIBRATIONS IN DIFFERENT TRANSFER CONDITIONS

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Abstract: The vibration transmitted through the seat of a four-wheel drive tractor, developing 179 kW, and equipped with front suspension axle and shock absorber for the implement, were measured and analysed according to the ISO standard. Several tests were carried out in different conditions considering: type of operation (transfer with and without mounted implement); type of track (conglomerate bituminous road, country lane); connected and disconnected suspension and/or shock absorber; and forward speeds. For the transfer on bituminous conglomerate road, it was observed that the suspension always reduces acceleration a_v, in both tests without and with implement, for all the considered forward speeds. For the tests conduced on country lane, the front axle suspension involved a reduction of the acceleration, but it was less evident than on the road Results showed that the forward speed and the mass distribution were the most important factors on tractor behaviour influencing the driver comfort. The daily exposure time which could compromise the driver's health increased from 2.5 to 8 h decreasing the speed from 3.06 to 2.22 m/s during transfer in country lane without implement. In the other condition the time exposure is approximately more than a working day.

INTRODUCTION

Agricultural tractors are extensively used for on-road and off-road transportation and for different field operations. It is widely recognized that tractor drivers are exposed to high levels of whole-body vibration during farm operations (Scarlett *et al.*, 2007). The transition towards increased forward speeds in agriculture introduces new technical problems related to dynamic behaviour and the exposure of tractor drivers to high levels of whole-body vibration during on-road and off-road transportation and during field operations (Servadio et al. 2007). The study of the problem of vibration transmission through the agricultural tractors seat to the conducers has been widely discussed during the last 40 years (Rossenger & Rossenger,1960; Matthews, 1964a and 1964b). The behaviour of tractor-seat-driver system was studied under standardized condition (Deboli &Potecchi, 1986) following the basis of international standard on whole body vibration (ISO 2631-1).

Lines *et al.* assessed the vibration transmitted from both suspended and unsuspended tractors during different task according with the international standard, was it also demonstrated that transport involves the highest vibration level and risk for the driver safety. Reduction in vibration for tractors equipped with passive or active systems (cab suspensions, axle suspension) have recently been studied and reported in literature (Biondi, 1999; Göhlich *et al.*, 1999). The combination of different systems as axle suspension and three point linkage shock absorber could not give positive results in dumping vibration transmission depending on forward speeds and tractor configuration (Marsili *et al* 2002). An improvement of comfort can be achieved also reducing the inflation pressure or choosing the correct type of tyres (Ulrich, 1983; Lines and Young, 1989).

In accordance with ISO standard on vibration assessment, the following research gives more results on the effect of an active front axle suspension and an active three-point linkage shock absorber mounted in a four-wheel drive tractor in order to dumping down vibrations.

MATERIAL AND METHOD

A four-wheel drive tractor 6 cylinder diesel common-rail developing 179 kW (2000/25/CE) was used in the test. The tractor is equipped with an active suspension installed on the front axle, an inactive suspended cab and an active pneumatic seat. The hydro-pneumatic system of the suspension adapted itself to the varying loads. It is composed of a two hydraulic cylinder, a position sensor, two nitrogen shock absorbers with the purpose of handling the suspension and a group of electric valves. The suspended cab is designed as a rollover protective structure (ROPS) to protect the operator in case of tractor turnover. In the front part of the cab there were hydraulic supports, while in the rear there are springs and shock absorbers. The seat for the driver is suspended by a pneumatic suspension, automatically adjustable according to the driver's mass, integrated with a hydraulic damper.
The tractor includes also a three-point linkage shock absorber

The tests were conduced on two different tracks with different forward speeds:

- rectilinear plane tract on bituminous conglomerate road with four speeds 9.44 m/s, 10.27 m/s, 11.11 m/s, 12.22 m/s.
- rectilinear plane tract of country line track with two speeds 2.22 m/s and 3.06 m/s.

Two different configuration of the tractor where tested in both conditions: tractor without any implement; tractor implemented with a plough (1450 kg of mass) on the back three-point linkage and with ballast (in the front three-points linkage; 1400 kg of mass).

The instrumental chain for evaluating the vibration in term of RMS weighted acceleration and the ride comfort index (c_i) (ISO 2631-1/1997) was based of a eight channels data recorder (TAEC 135-T), a triaxial accelerometer (PCB 356B41) for the evaluation of the vibration along the three axes (x, y, z). The axes were oriented as follows: x, back-front (back-chest); y, lateral (driver's right side to left side) and z, vertical (pelvis to head). Vibrations were analyzed in 1/3 octave band from 0.5 to 80 Hz. The root mean square (r.m.s.) values, obtained for each 1/3 octave band, were used to calculate the global frequency-weighted acceleration a_{wx}, a_{wy}, a_{wz}, for each axis, and then combined to obtain the value of the acceleration vector sum a_v, in ms^{-2}, where:

$$a_v = [(1.4a_{wx})^2+(1.4\ a_{wy})^2+a_{wz}^2]^{0.5}$$

a_{wz} values were compared with the exposure criteria curves (ISO 2631-1/1997), to give some indications about the health risk of vibration transmitted through the seat to the driver. The daily exposure time T_d to reach the lower boundary of the “health guidance caution zone” was calculated as:

$$T_d = \left(\frac{a_{wz}}{9.4848}\right)^{-2}$$

The ride comfort index (c_i) was calculated as the acceleration vector sum by using the following formula:

$$c_i= [k_x a_{wx}^2+k_y a_{wy}^2+k_z a_{wz}^2]^{0.5}$$

where the k_x, k_y, k_z values is 1.

Acceptable values of vibration magnitude for comfort depend on many factors which vary with each application and in term of comfort reactions to vibration environments. Therefore, a limit is not defined in ISO 2631, so the following values give approximate indications of likely reactions to various magnitudes of comfort index in public transport:

Less than 0.315 m/s^2	not uncomfortable
0.315 m/s^2 to 0.63 m/s^2	a little uncomfortable
0.5 m/s^2 to 1 m/s^2	fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	uncomfortable
1.25 m/s^2 to 2.5 m/s^2	very uncomfortable
Greater than 2 m/s^2	extremely uncomfortable

RESULTS AND DISCUSSIONS

In tables 1and 2 are reported the values of weighted accelerations for the three axis a_{wx}, a_{wy}, a_{wz} and the corresponding vector sum a_v, for the different test. For the transfer on bituminous conglomerate road (Table 1), it was observed that the suspension always reduces acceleration a_v, in the tests both without and with the implement, for all the considered forward speeds. It is possible to notice that the weighted accelerations a_{wz} and a_v measured at at 10.27 m/s in both tests were higher than that measured at 11.11 m/s.

Table 1

Values for the global frequency-weighted r.m.s. acceleration a_{wx}, a_{wy}, a_{wz} for each axis and acceleration vector sum a_v for the tests on bituminous conglomerate road.

State of the dumping device		*Transfer without implement*				*transfer with plough*			
		Speed ms^{-1}				*Speed* ms^{-1}			
	Parameter	*12.22*	*11.11*	*10.27*	*9.44*	*12.22*	*11.11*	*10.27*	*9.44*
Suspension: Off	a_{wx}, ms^{-2}	0.438	0.191	0.222	0.166	0.228	0.222	0.139	0.141
Shock absorber: Off	a_{wy}, ms^{-2}	0.132	0.092	0.083	0.093	0.105	0.092	0.121	0.083
	a_{wz},ms^{-2}	0.559	0.393	0.577	0.375	0.424	0.233	0.303	0.193
	a_v, ms^{-2}	0.850	0.492	0.666	0.460	0.551	0.409	0.398	0.300
Suspension: On	a_{wx}, ms^{-2}	0.203	0.132	0.097	0.124	0.1	0.094	0.079	0.103
Shock absorber: Off	a_{wy}, ms^{-2}	0.122	0.099	0.101	0.085	0.127	0.098	0.085	0.084
	a_{wz},ms^{-2}	0.311	0.312	0.274	0.31	0.15	0.143	0.147	0.149
	a_v, ms^{-2}	0.455	0.388	0.337	0.375	0.272	0.238	0.219	0.238
	□, %	-46.52	-21.17	-49.38	-18.54	-50.70	-41.87	-44.95	-20.42
Suspension: On	a_{wx}, ms^{-2}	—	—	—	—	0.114	0.117	0.085	0.113
Shock absorber: On	a_{wy}, ms^{-2}	—	—	—	—	0.106	0.077	0.078	0.071
	a_{wz},ms^{-2}	—	—	—	—	0.212	0.205	0.181	0.188
	a_v, ms^{-2}	—	—	—	—	0.304	0.284	0.243	0.265
	□, %					-44.79	-30.68	-39.04	-11.51

This could be explained through a front tyres resonance and through the increasing of disturbing frequencies at that speed; this phenomenon disappears if the suspension is activated. The reduction in a_v due to active suspension range from 18% to about 50% for tractor without implement, and from 20% to 50% for the tractor implemented with plough. The maximum reductions were registered for the speed subjected to the above decrypted phenomenon and increased basically by the speed increasing. The combination of suspension and shock absorber always involved a worst reduction (from 11% to 45%) in term of a_v. For this test, considering acceleration value a_{wz} only, the daily exposure time T_d increased with the decrease of speed of about 54%. However, in all conditions of this test the T_d value resulted longer than a working day (8h). For the test conduced on country lane (Table 2), the front axle suspension involved a reduction of the acceleration $a_{v,}$ but it was less powerful than on the road (about 5% without and 13% with the plough). The combination of suspension and shock absorber always involved a reduction in a_v, but it was considerably lower than that obtained by activating only the suspension (about 9% for the highest speed and 1.4 % for the lower speed). For this test, the daily exposure time T_d increased with the decrease of speed of about 70%. The daily exposure time T_d in the transfer on country lane was increased by the front axle suspension of 22% without implement and more than 43% with the plough. The daily exposure time rose from 2.5 h, at 3.06 m/s of speed without implement, to 8.5 h at 2.22 m/s. The only values of T_d which can be taken in to account were those measured for the highest speed without and with the front axle suspension and with implement but without suspension. The others are longer than a working day.

Table 2
Values for the global frequency-weighted r.m.s. acceleration a_{wx}, a_{wy}, a_{wz} for each axis and acceleration vector sum a_v for the tests on country lane.

State of the dumping device	*Parameter*	*Transfer without implement* *Speed ms^{-1}* *3.06*	*2.22*	*Transfer with plough* *Speed ms^{-1}* *3.06*	*2.22*
Suspension: Off	a_{wx}, ms^{-2}	0.492	0.272	0.389	0.289
Shock absorber: Off	a_{wy}, ms^{-2}	0.536	0.415	0.377	0.226
	a_{wz},ms^{-2}	0.759	0.415	0.657	0.281
	a_v, ms^{-2}	1.270	0.809	1.003	0.585
Suspension: On	a_{wx}, ms^{-2}	0.477	0.262	0.397	0.199
Shock absorber: Off	a_{wy}, ms^{-2}	0.543	0.407	0.397	0.257
	a_{wz},ms^{-2}	0.644	0.366	0.377	0.213
	a_v, ms^{-2}	1.199	0.770	0.872	0.502
	□, %	-5.58	-4.82	-13.12	-14.18
Suspension: On	a_{wx}, ms^{-2}	—	—	0.415	0.199
Shock absorber: On	a_{wy}, ms^{-2}	—	—	0.415	0.304
	a_{wz},ms^{-2}	—	—	0.425	0.275
	a_v, ms^{-2}	—	—	0.925	0.578
	□, %			-8.99	-1.44

Results have shown that the forward speed and the mass distribution were the most important factors on tractor behaviour influencing the driver comfort.

The values of the comfort index are given in tables 3 and 4. For the transfer on the bituminous conglomerate road the comfort index, tended to increase increasing the speed but not always the increase of speed gave an increase of acceleration. It is evident the effect of the mass distribution on the comfort values for the tractor with and without implement. While the tractor without implement was *fairly uncomfortable* when the speed increased, the tractor with implement was *not uncomfortable* and, just for the highest speed *a little uncomfortable* (ISO 2631-1/1997).

The front axle suspension reduced the index from 18% to 45% when the speed increased during transfer without implement and from 21% to 55% for those with implement. The reduction for combined front axle and shock assistant increased with the speed from 9% to 46%. In both conditions the comfort index can be considered *not uncomfortable.*

Table 3
Comfort index c_i for the tests on bituminous conglomerate road.

State of the dumping device	*Parameter*	*Transfer without implement* Speed ms^{-1}				*transfer with plough* Speed ms^{-1}			
		12.22	*11.11*	*10.27*	*9.44*	*12.22*	*11.11*	*10.27*	*9.44*
Suspension: Off Shock absorber: Off	c_i, ms^{-2}	0.722	0.447	0.624	0.421	0.493	0.439	0.355	0.253
Suspension: On Shock absorber: Off	c_i, ms^{-2}	0.391	0.353	0.308	0.345	0.221	0.197	0.187	0.200
Suspension: On Shock absorber: On	c_i, ms^{-2}	—	—	—	—	0.263	0.248	0.215	0.231

Table 4
Comfort index c_i for the tests on country lane.

State of the dumping device	*Parameter*	*Transfer without implement* Speed ms^{-1}		*Transfer with plough* Speed ms^{-1}	
		3.06	*2.22*	*3.06*	*2.22*
Suspension: Off Shock absorber: Off	c_i, ms^{-2}	1.051	0.647	0.852	0.462
Suspension: On Shock absorber: Off	c_i, ms^{-2}	0.968	0.607	0.676	0.389
Suspension: On Shock absorber: On	c_i, ms^{-2}	—	—	0.725	0.456

The results in term of comfort (table 4) for the transfer without and with implement on country lane shoed level of c_i considered from *fairly uncomfortable* to *uncomfortable.* For the tractor without implement, the activation of the front axle suspension did not involve a reduction (about 7%) capable to improve the comfort. The activation of front axle suspension and the different mass distribution in tractor with implement caused a slight improvement of comfort. The combined action of the front axle suspension and shock absorber did not affect the c_i values.

CONCLUSIONS

The active front axle suspension mounted on the tested tractor showed, in all cases, a substantial attenuation of the global acceleration transmitted to the driver's seat during transfer on different tracks, without and with an implement. The decrease in acceleration was similar in the test without and with an implement on bituminous conglomerate road: from 20 to 50%. The effects on vibration transmission due to the combination of the three point shock absorber and the active front axle suspension for the different test track conditions were in all cases less evident as a_v reduction, but the combination of the devices often seemed to cause an amplification of the global acceleration. The tractor configuration and the activation of two devices affected the comfort which appeared *fairly uncomfortable* without implement and/or devices and *not uncomfortable* with implement and/or devices on the bituminous conglomerate road. On the country lane the results for the comfort index seemed more affected by the mass distribution then the application of the two devices. The values ranged from *fairly uncomfortable* to *uncomfortable* for the forward speed 2.22 and 3.06 m/s respectively. The daily exposure time which could compromise the driver's health increased from 2.5 to 8 h decreasing the speed from 3.06 to 2.22 m/s during transfer in country lane without implement. In the other condition the time exposure is approximately more than a working day.

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