Assessment of Comfort Conditions of an Agricultural Tractor During Operations with Plough on Digh Roughness Surface

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Abstract
For agricultural tractors irregularity of working terrains and forward speed are the most important causes of vibrations transmitted to the driver and on tool oscillations.
A typical situation of high roughness surface is that of working with the tractor on the perpendicular of the way of seeding, this working procedure has to be adopted for combining the shape of the field with the location of the irrigation source.
The CRA-ING research unit has investigated the influence on operator's comfort of a tractor during plowing in different conditions.
The roughness of the field was, as expected, the most important factor affecting driver's comfort. The increasing speed had influence on comfort value but not linearly for the effect of the resonance of the tires at certain speeds. Beside, during ploughing the discomfort was always lower than on transport on field.

Keywords: safety, vibrations, transport

Introduction

The professional drivers are exposed at whole body vibrations and, in particular, agricultural vehicle operators could be at risk of high levels of exposure.
The protection of workers is reported in the European Parliament Directive 2002/44/EEC (EEC, 2002), that defines the minimum safety requirements. Moreover, in 2008, Italy adopted a specific national regulation on safety (Decree no. 81/2008).
For agricultural tractors, considering normal conditions of use, irregularity of working terrains and forward speed are the most important causes of vibrations transmitted to the driver (Scarlett et al., 2002), on tool oscillations and impact on work quality (Bisaglia et al., 2006).
A typical situation of high roughness surface is that of working with the tractor on the perpendicular of the way of seeding, this working procedure has to be adopted for combining the shape of the field with the irrigation source.
The CRA-ING research unit has investigated the influence on operator's comfort of a tractor during ploughing in different conditions. Tests aimed to evaluate the ride comfort index (CI) and the safety level of the driver measuring the accelerations at the three axis of the back and of the seat. In particular, the study reports the comparison of the evaluation of the risk for the operator working with tractor on terrains with high roughness surface with ploughing on smooth surfaces.

Methods

The guidelines followed for the measurement of operator's safety and comfort were those established by the ISO 2631/1997, European Parliament Directive 2002/44/EEC and Italian Decree on safety no. 81/2008.
A 4WD tractor fitted with a plough (820 kg) and a front ballast (600 kg) has been used.
The tires were 540/65 R24 on the front and 600/65 R38 on the rear at 120 kPa.
The variables chosen for the test were the following:

- different levels of roughness: L, G;
- different forward speeds: 1.25, 1.39, 1.53, 1.67, 1.94, 2.08 ms^{-1};
- on the same line and on the perpendicular way of seeding: S, T;
- ploughing and transport on terrain: P; N

The mean values of the roughness of the surface were:

- TL = 40 mm (std dev = 5,32)
- TG = 79,6 mm (std dev = 17,56)

The forward speeds have been selected compatibly with the tractor gearbox and could change of +/- 0.07 ms^{-1} for the wheel slipping.
The complete list of the tests carried out is reported in table 1.

Table 1: The settings adopted for the test

Speed (ms^{-1})	1.25	1.39	1.53	1.67	1.94	2.08
PS	X	X	X	X	X	
PTL	X	X	X	X	X	
PTG	X	X	X	X	X	X
NS	X	X	X	X	X	X
NTG	X	X	X	X	X	X
Asf	X	X	X	X	X	X

The vehicle has been instrumented with a set of two triaxial accelerometer (range ±50 g, sensitivity 100 mV/g) placed in correspondence of the seat surface and of the back to evaluate the operator comfort.

Results
Apart the Asf condition that is used only as "zero reference" of the ground and of the tractor, the values of the equivalent level of daily exposure (A8) measured as safety were from 0.53 to 1.42 ms^{-2}.
The lowest values were obtained in the PS condition from 0.53 to 0.7 ms^{-2} respect to the highest values obtained in the NT configuration from 1.09 to 1.42 ms^{-2}.
The increasing forward speed increases the value of exposition to vibration also if not linearly and also if the highest value could not be at maximum tested speed for the influence of the resonance conditions of the tires.
Considering the results at the same speed, the roughness of the surface increases dramatically the discomfort value passing from values of 0.5 ms^{-2} for the PS condition to 1.2 ms^{-2} of the NTG condition and from 0.8 ms^{-2} of the NS condition to 1,4 ms^{-2} of the NTG condition.
The roughness resulted the factor more influencing the comfort, beside we've to consider the high difference between the activity of ploughing and of transport characterised from the different load on soil of the tractor. The activity of transport on field is always much more discomfortable than ploughing.
The measurements are reported in table 2.

Table 2: The A8 equivalent acceleration value for the operator safety.

Speed (ms^{-1})		1.25	1.39	1.53	1.67	1.94	2.08
A8 (ms^{-2})	PS	0.7	0.658	0.63	0.532	0.588	NA
	PTL	0.644	0.7	0.798	0.85	0.95	NA
	PTG	0.672	0.79	1.2	1.16	1	1.05
	NS	0.644	0.728	0.728	0.812	1.33	0.896
	NTG	1.15	1.13	1.38	1.42	1.23	1.092
	Asf	0.154	0.19	0.16	0.11	0.13	0.12

The risk analysis is obtained applying the Italian Directive n°81/2008 on safety. The action value is 0.5 ms^{-2} and has been always reached in all conditions, apart, as expected in Asf setting.
The safety limit is 1 ms^{-2} on the 8 hour daily work and it's possible to see how has been reached in PTG and NTG configuration. Beside an important novelty of the Italian Directive is a superior limit of 1.5 ms^{-2} over which is possible to work only for brief period. This has to be considered as no value on the 8 hour has reached the 1.5 ms^{-2} but we've to note the situations of NTG at 1.53 and 1.67 ms^{-1} that are very close.
The comfort analysis confirms the results obtained in the safety.
The condition PTG and NTG resulted extremely uncomfortable (>2 ms^{-2}) but all the values resulted always in the uncomfortable trend (>0.8 ms^{-2}).
The results are reported in table 3 and, as expected, all the considerations of safety are confirmed.

Table 3: The results of the comfort analysis.

Speed (ms^{-1})		1.25	1.39	1.53	1.67	1.94	2.08
A8 (ms^{-2})	PS	0.897	0.93	0.857	0.79	0.868	NA
	PTL	1.143	0.979	1.194	1.533	1.735	NA
	PTG	1.097	1.51	2.17	2.07	1.74	1.711
	NS	0.86	1.01	1.055	1.119	1.94	1.797
	NTG	2.307	2.208	2.59	2.6	2.2	1.85
	Asf	0.213	0.267	0.246	0.167	0.2	0.181

For better understanding the spreading of vibration on the operator it's necessary to analyse the components of the ride comfort that were the seat (S) and the back (B).
The values obtained were always very similar but some consideration can be carried out.
In PS, PTL and NS conditions, the values at the seat is greater than at the back while in case of high roughness surface the situation was different indicating that the growing roughness influences above all the pitching than the vertical pumping of the vehicle.

Table 4: Comfort analysis of the channels seat (S) and back (B).

Speed (ms^{-1})		1.25		1.39		1.53		1.67		1.94		2.08	
Channel		S	B	S	B	S	B	S	B	S	B	S	B
A8 (ms^{-2})	PS	0.74	0.51	0.75	0.55	0.7	0.5	0.63	0.47	0.67	0.55	-	-
	PTL	0.92	0.67	0.76	0.62	0.91	0.78	1.05	1.12	1.23	1.22	-	-
	PTG	0.81	0.74	1.01	1.12	1.45	1.62	1.37	1.55	1.21	1.25	1.25	1.17
	NS	0.66	0.55	0.76	0.67	0.78	0.71	0.83	0.75	1.4	1.34	1.32	1.22
	NTG	1.51	1.75	1.46	1.66	1.7	1.96	1.75	1.92	1.58	1.53	1.35	1.26
	Asf	0.17	0.12	0.22	0.16	0.19	0.15	0.13	0.1	0.16	0.12	0.14	0.11

This phenomena is clearer analysing the axis of solicitation always at the back and at the seat.

In fact reducing the analysis at the roughness surface it's possible to see that at the seat the highest value is always the Sz and at the back is always the Bx.
In the other situations, not reported as data in the paper, the channels' values are near and, in particular, the Sy and By values are of the same level of the x and z channels.

Table 5: Comfort analysis of the single channels of the seat (S) and of the back (B).

Speed (ms^{-1})		1.25		1.39		1.53		1.67		1.94		2.08	
Setting		PTG	NTG	PTG	NTG	PTG	NTG	PTG	NTG	PTG	NTG	PTG	NTG
A8 ms^{-2}	Sx	0.45	0.74	0.4	0.67	0.59	0.82	0.46	0.86	0.48	0.82	0.49	0.78
	Sy	0.48	0.7	0.54	0.7	0.64	0.63	0.63	0.66	0.56	0.65	0.75	0.59
	Sz	***0.5***	***1.15***	***0.79***	***1.13***	***1.2***	***1.38***	***1.16***	***1.42***	***1***	***1.23***	***0.91***	***0.98***
	Bx	***0.87***	***2.15***	***1.38***	***2.04***	***2***	***2.43***	***1.92***	***2.38***	***1.54***	***1.86***	***1.39***	***1.52***
	By	0.48	0.7	0.54	0.7	0.64	0.63	0.63	0.66	0.56	0.65	0.75	0.59
	Bz	0.45	0.74	0.4	0.67	0.59	0.82	0.46	0.86	0.48	0.82	0.49	0.78

The roughness of the field was. as expected. the most important factor affecting driver's comfort. The increasing speed had influence on CI value but not linearly for the effect of the resonance of the tires at certain speeds depending from the distance of seeding line (0.7 m). Beside. during ploughing the CI value was always lower than on transport on field.
The requirements of the Italian Directive of 2008 on safety resulted of particular interest in operations with plough and have to be taken into account and analysed for driver's risk analysis.
After verifying the conditions of normality and homoscedasticity on results, was conducted the analysis of variance that showed statistically significant influence of setting conditions in study on the values obtained from all accelerometers (p-value <0.05). Repeats showed no influence on the results (p> 0.70).
For the evaluation of differences between the averages was performed the Tukey test (Tab.6) for detecting the minimum significant difference between the means obtained in the variation of the factor surface and resulting in variations of the speed factor, against the ride number and its components.

Table 6: Tuckey test on the Ride number

Settings	RN Average	Speed ms^{-1}	RN Average
AL	0.86148 e	1.25	1.04708 c
Asf	0.21497 f	1.39	1.12646 c
ATG	1.67427 b	1.53	1.32556 b
ATL	1.28268 c	1.67	1.33622 ab
NL	1.15992 d	1.94	1.41674 a
NT	2.30915 a	2.08	

The same processing was performed (Table 7) on the averages obtained from 30 combinations. It highlighted average groups statistically homogeneous as in the case of the Asf setting.

Table 7: Tukey test on the Ride number

Settings	Speeds	RN Average
AL	1.25	0.49203 n
	1.39	0.54897 lm
	1.53	0.50043 mn
	1.67	0.47110 n
	1.94	0.55637 lm
Asf	1.25	0.11853 o
	1.39	0.15970 o
	1.53	0.14530 o
	1.67	0.09727 o
	1.94	0.12287 o
ATG	1.25	0.72690 hi
	1.39	1.09287 g
	1.53	1.58033 bc
	1.67	1.54357 cd
	1.94	1.17343 fg
ATL	1.25	0.65097 hi
	1.39	0.59110 jl
	1.53	0.75207 h
	1.67	1.06710 g
	1.94	1.23923 ef
NL	1.25	0.53367 lm
	1.39	0.62527 ij
	1.53	0.70290 hi
	1.67	0.68677 hi
	1.94	1.33467 e
NT	1.25	1.67567 b
	1.39	1.64483 bc
	1.53	1.90543 a
	1.67	1.85953 a
	1.94	1.45837 d

The Tukey test showed within each group corresponding to the setting test, some average which deviate from the average speed of the group in almost every setting. This is especially true in cases which have the highest ride number and this suggests a connection with effects of the resonance of the tires.

Conclusions

The CRA-ING research unit has investigated the influence on operator's comfort of a tractor during plowing and transport on terrain surfaces of different roughness and at different speeds.

The roughness of the field was, as expected, the most important factor affecting driver's comfort. The increasing speed had influence on comfort value but not linearly for the effect of the resonance of the tires. The activity of transport on field was always more discomfortable than that of plowing.

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REFERENCES

Bisaglia. C., Cutini. M. and Gruppo. G. 2006. Assessment of vibration reproducibility on agricultural tractors by a "four poster test stand". Proceedings of the XVI CIGR. EurAgEng 2006. 64th VDI-MEG and FAO joint "World Congress - Agricultural Engineering for a Better World". Bonn. Germany : s.n.. September 3-7. 2006. pp. 1-6.

Bukta A. J. K., Sakai. A., Sasao. S., Shibusawa 2002. "Free play as a source of non linearity in tractor-implement systems during transport". Applied Engineering in Agriculture; vol.45(3): 503-508

Chiang. C.F. and Liang C. C. 2006. A study on byodinamic models of seating human subjects exposed to vertical vibration. International Journal of Industrial Ergonomics. 2006. Vol. 36. pp. 869-890.

Cutini M., Bisaglia C., Romano E. 2007. "Assessment of tractor's tires influence on operator's confort". Advances in Labour and Machinery Management for a Profitable Agriculture and Forestry. Nitra. Slovakia. Conference Proceedings pp.183-189

Directive 2002/44/EC. 2002. Minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). Official Journal. 2002. Vols. L 177 . 06/07/2002 P. 0013 - 0020.

Hostens I.J., Anthonis P., Kennes H., Ramon. 2000. Six-degrees-of-freedom test rig for simulation of mobile agricultural machinery vibration. Journal of Agricultural Engineering Research 77(2); 155-169

ISO standard 2631-1. 1997. Mechanical vibration ad shock - Evaluation of human exposure to whole-body vibration. 1997. Vol. Part. 1: General requirements.

Okunribido O., Magnusson M., Pope M. H. 2006. Low back pain in drivers: The relative role of whole body vibration. posture and manual materials handling. Journal of Sound and Vibration Vol. 298 (3). 540-555.

Scarlett A. J., Price J. S., Stayner R. M. 2007. Whole body vibration: Evaluation of emissions and exposure levels arising from agricultural tractors. Journal of Terramechanics. 44. 65-73.

Seidel, Helmut and Heide. Renate. 1986. Long-term effects of whole-body vibration: a critical survey of the literature. International Archives of Occupational and Environmental Health. s.l. : Springer Berlin / Heidelberg. 1986. Vol. 58. 1. pp. 1-26.