Investigation of the vibrations transmitted by agricultural tractor to the driver under operative conditions

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Abstract

Professional risk from mechanical vibrations is contemplated, in the national legislation, by the Legislative Decree 187/05, receiving the 2002/44/CE Directive that indicates the minimum prescriptions, in safety and health matter, concerning workers' exposure to the risk from vibrations.

From an health point of view, the vibrations transmitted to the workers are traditionally classified as whole body vibrations or hand harm system vibrations.

The present paper took into consideration the levels of the whole body vibrations transmitted to the drivers by a series of agricultural tractors of different dimensions and power, under typical conditions of utilisation. The tests have been conducted according to the ISO 2631-1:1997 standard concerning the measurement of vibration levels at the driver seat.

Each tractor has been used in two operations typical for its characteristics, using proper operating machines, with the aim of characterizing the level of vibrations produced by each operation, in terms of total acceleration, axial acceleration and time of exposure, calculated by means of a suitable Excel data-sheet, providing both the "limit value" and the "safety value".

Keywords: work, vibrations, tractor, safety.

Introduction

Professional risk from mechanical vibrations is contemplated, in the Italian legislation, by the Legislative Decree 187/05 [1], receiving the 2002/44/CE Directive [2] that indicates the minimum prescriptions, in safety and health matters, concerning workers' exposure to the risk from vibrations.

As they represent, in Italy, one of the most diffused and unknown causes of pathologies, a specific policy of prevention has been started against them.

Considering the exposure of the workers to the vibrations, these are traditionally classified as whole-body vibrations and hand-arm system vibrations. As regards to the whole-body vibrations, it is estimated that, in Europe, 4% up 6% of the craftwork is regularly exposed to high intensity vibrations, capable to determine health damages, particularly on the lumbar rachis [3].

The decree of above reports two time values for the exposure to the whole-body vibrations, the "limit value" and the "action value" (table 1), determining some obligations.

From a technical point of view, the test procedures for the measurement and evaluation of whole-body vibrations are reported in the ISO 2631-1:1997 standard [4]. It allows to estimate the effects of the vibrations on health and comfort.

Table 1. Daily exposure to vibrations: limit and action values according to the Lgs. D. 187/05

	Limit value (ms^{-2})	Action value (ms^{-2})
Whole body	1,15	0,50

In such a picture, a study has been started with the aim of investigating the levels of whole-body vibrations generated by using tractors in agricultural works. The study regarded a series of tractors with different characteristics of dimensions, power and use. The sample of tractors has been chosen with the purpose of being representative of the wide range of possibilities offered by the market. Each tractor has been observed in field, during the execution of operations typical for it.

Materials and methods

<u>Measured parameters, data processing and reference parameters</u>

The basic parameter to measure, in the evaluation of the level of vibrations, is the acceleration, *a,* expressed in ms^{-2}.

As the effects of the vibrations depend on the frequency of the accelerations, these must be weighted by means of suitable filters, according to the standards [4].

The weighting filters are calculated as a function of the human body sensitiveness to the acceleration in the different sampling frequencies and provide an acceleration value called frequency weighted acceleration, a_w,

$$a_W = \left[\frac{1}{T} \int_0^T a_w^2(t) dt \right]^{\frac{1}{2}}$$

where:
$a_W(t)$ is the measured value of the acceleration;
T is the acquisition time interval in seconds.

The three components of the acceleration along the x, y and z axes are measured and the resulting total acceleration a_v is provided by the relation:

$$a_v = (k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2)^{\frac{1}{2}}$$

where:
a_{wx}, a_{wy}, a_{wz} are the weighted r.m.s. accelerations along the x, y and z axes;
k_x, k_y, k_z are indices the values of which has been determined depending of the effects of the relative components of the acceleration on the health: fir k_x e k_y a value of 1.4 is applied in the case of sitting positions as they are equal to 1 for the upright position; k_z is equal to 1 in both positions.

<u>Determination of the acceleration level referring to the daily exposure time</u>

In general, the total value of the acceleration a_v, measured during the daily exposure time (T_e), must be normalized referring to the 8 hours time interval, according to the principle of "equal energy". The normalized value of acceleration, *A(8)*, is calculated by means of the formula:

$$A(8) = a_v \sqrt{\frac{T_e}{8}}$$

By means of this formula, basing on the comparison between A(8) and the standard limits values given for the 8 hours time, the time of exposure to a_v can be determined. The values of A(8) are: the "daily action value" and the "limit value" of tab 1, providing, respectively, the "safety time" and the "limit time". If the safety time is not exceeded, the exposure to vibrations does not determines the occurrence of pathologies on an operator in normal health conditions. In the case of whole-body vibrations, the determination of A(8) is made using, instead of a_v, the highest axial component, among a_{wx}, a_{wy}, a_{wz} , multiplied by the relative index k (1.4 for the x and y axes and 1 for the z axis).

Instruments

The figure 1 shows the instrumental chain use in the tests. It was composed by:

- a tri-axial accelerometer for driver seat Brüel & Kjær, type 4322;
- an 8-channel digital recorder DAT-Herm;
- two signal conditioners Brüel & Kjær mod. 'Nexus';
- a signal acquisition and processing system Brüel & Kjær, mod. Pulse;
- a calibrator for accelerometers Brüel & Kjær, tipo 4294.

Figure 1. Instrumental chain A) triaxial accelerometer for driver seat; B) 8-channels digital recorder; C) 6-channell signal conditioners; D) "Pulse" data processing system

Characteristics of the machines

The tests have been conducted on 10 tractors with different power, mass and utilization (Tab. 2). The tractor have been tested during the execution of two operations typical for each of them (fig. 2), under the usually adopted conditions of velocity, power-take-off speed. etc., also depending on the type of operating machine used.

Table 2. Main characteristics of the tested tractors and test conditions

Tractor No.	Power (kW)	Mass (Kg)	Operation	Velocity (Km/h)
1	51,5	2280	Chopping Distribution of chemicals	4,0 5,7
2	54,5	2270	Chopping Distribution of chemicals	6,2 7,2
3	58,8	2955	Harrowing Chopping	
4	70,5	3150	Ploughing Hay harvest	4,0 7,9
5	70,5	4055	Ploughing Sowing Earthworks	4,0 8,0 --
6	70,0	4150	Ploughing Harrowing	5,4 7,2

7	87,0	4850	Ploughing Harrowing	5,1 5,4
8	103,0	6420	Ploughing Harrowing	
9	157,0	7520	Ploughing Harrowing	3,8 5,2
10	205,0	11000	Ploughing Harrowing	6,0 8,0

The tractor No. 1 is characterized by low seat, high manoeuvrability and compact frame that make it suitable for the use in row cultivations (fructiculture and horticulture), in small farms and in works requiring the p.t.o. as a power source.

No. 2 is fitted up with some advanced technical solution increasing the level of comfort and performances. Because of a good mass/power ratio, it cab be conveniently used on soils sensitive to compaction, as the front axle with a 55°steering angle makes it suitable for manoeuvres in narrow spaces. It can be used in a wide range of operations, from soil refinement to crop protection, from hay harvest to farm works and road transport.

No. 3 is a 4WD tractor for universal use. In the tests, the engine speed has been adjusted on the value of 2067 min^{-1} corresponding to a p.t.o. speed of 540 min^{-1}, for driving a chopper.

No. 4 is a simple tractor, easy to use and suitable for field works in small and medium farms.

No. 5 with a power similar to the previous one, is a modern tractor with high performances equipped with a drooping cowling that increases la visibility, a power-shift gear box, an electronic lift and an automatic system that electronically controls the traction.

No. 6 is a robust and reliable tracked tractor suitable for works in hard soils and under high slope conditions. The function of dumping of the vibrations is operated by the platform supporting the seat, that is suspended on silent-block.

No. 7 is a medium power, modern tractor characterized by high versatility in the different operative situation, from the field to the road transfer, guarantying a good level of comfort and ergonomics to the driver. It is equipped with a self- front axle and with both front and rear p.t.o. electro-hydraulically controlled.

No. 8 is a 4WD, medium power tractor of universal use.

No. 9 is a medium power tractor equipped with a hydraulic suspension at the front axle. Moreover, an automatic electro-hydraulic system operates the self-levelling of the cab under slope conditions, increasing the comfort for the driver.

N. 10 is an high power modern tractor largely used in field works and transport operations.

Figure 2. Some of the tested tractor during field works: Left: Tractor No. 9 in harrowing; right: tractor No. 10 in ploughing

The driver seat represents the element through which most of the vibrations generated by the interaction among soil, tractor and operating machine are transmitted to the driver's body.

In the tractors no. 1, 2, 3, 4 and 6 the suspension of the driver seat is based on a four-bar linkage with a central hydraulic cylinder and on a system of springs for the damping of the vertical accelerations. The stiffness of the springs is adjusted by rotating a knob in the lower part of the seat. In the tractors no. 5, 7, 8, 9, e 10 the adjustment of the driver seat suspension is operated by means of a pneumatic device that controlling the air pressure basing on the mass of the driver.

During the tests, the inflation pressure for both front and rear tyres has always been set on the values indicated in the ETRTO standard.

<u>*Methodology test*</u>

The measurements have been made according to the methodology reported in the ISO 2631-1:1997 standard [4]. The tri-axial accelerometer at the driver seat has been oriented as shown in fig. 3. The values of a_{wx}, a_{wy} e a_{wz} have been simultaneously collected and calculated in the frequency interval 0.5 to 80 Hz.

The acquisition time has been 240 s and is considered significant for the characterization of the level of vibrations typical for each operation. Five replications have been made in each test condition.

The values of A(8) and of the resulting safety and limit time values have been calculated by means of a Microsoft-Excel work-sheet for the "calculation of the exposure to vibrations", available in the Website of the ENAMA (National Body for Agricultural Mechanization).

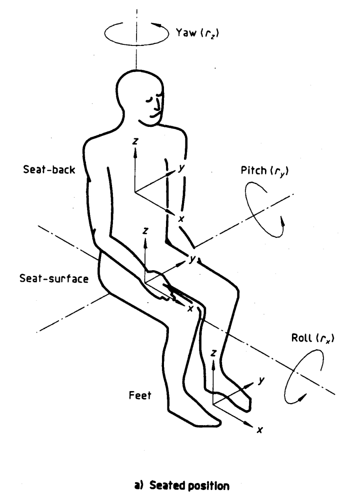

Figure 3. Systems to coordinate the relief vibration body defined by ISO 2631-1:1997

Results

The table 3 shows the values of the mean axial accelerations, a_{wx}, a_{wy}, a_{wz} , the values and the standard deviation of the resultant of the acceleration, a_v, the "safety time" and the "limit time". As said above, the times of exposure have been calculated on the basis of the highest axial value among a_{wx}, a_{wy}, a_{wz} , multiplied by 1.4 for the x and y axes and by 1 for the z axis [5] [6].

It can be noticed that in the tillage tests (ploughing and harrowing) the vector a_v always resulted higher than the daily limit value of 1.15 ms^{-2} fixed in the Directive.

Ploughing is the heaviest operation because of the shocks caused by the interaction among the force of traction, the characteristics of the plough, the coupling system and the characteristics of the soil, that determine severe work conditions from the point of view of the exposure to vibrations. As to the harrowing, aimed to the refinement of soil previously ploughed, the measured high vibration levels are mainly due to the high unevenness and cloddiness of the soil.

Table 3. Mean axial accelerations, a_{wx}, a_{wy}, a_{wz}, the values and the standard deviation of the resultant of the acceleration, av, found body during the main processing. - Time maximum daily use not to exceed the value of safety and the limit value

Test No.	Operation	a_{wx} (ms^{-2})	a_{wy} (ms^{-2})	a_{wz} (ms^{-2})	a_v (ms^{-2})	Standard Dev.	a_w (ms^{-2})	Safety time (a_v < 0,5) (h:min)	Limit time (a_v < 1,15) (h:min)
1	Chopping	0.280	0.333	0.541	0.833	0.241	0,541 (z)	6.18	> 12.00
	Distribution of chemicals	0.211	0.383	0.482	0.780	0.114	0,383 (y)	6.25	> 12.00
2	Chopping	0.241	0.414	0.771	1.02	0.052	0,771 (z)	3.06	> 12.00
	Distribution of chemicals	0.303	0.567	0.847	1.24	0.269	0,847 (z)	2.34	> 12.00
3	Harrowing	0.356	0.632	0.604	1.18	0.032	0,632 (y)	2.21	> 12.00
	Chopping	0.506	0.637	1.03	1.51	0.278	1,03 (z)	1.44	9.58
4	Ploughing	0.671	0.425	0.863	1.41	0.312	0,671 (x)	2.05	11.59
	Hay harvest	0.747	0.561	0.407	1.38	0.331	0,747 (x)	1.41	9.40
5	Ploughing	0.702	0.433	0.453	1.24	0.147	0,702 (x)	1.54	10.57
	Sowing	0.502	0.372	0.312	0.930	0.091	0,502 (x)	3.44	> 12.00
	Earthworks	0.494	0.361	0.328	0.918	0.181	0,494 (x)	3.51	> 12.00
6	Ploughing	0.523	0.661	0.800	1.43	0.052	0,661 (y)	2.09	> 12.00
	Harrowing	0.395	0.616	0.466	1.13	0.330	0,616 (y)	2.29	> 12.00
7	Ploughing	0.490	0.612	0.343	1.15	0.162	0,612 (y)	2.31	> 12.00
	Harrowing	0.527	0.835	0.356	1.43	0.127	0,835 (y)	1.21	7.45
8	Ploughing	0.410	0.374	0.427	0.888	0.070	0,410 (x)	5.36	> 12.00
	Harrowing	0.668	0.696	0.741	1.55	0.124	0,696 (y)	1.56	11.09
	Sowing	0.488	0.643	0.669	1.28	0.109	0,643 (y)	2.16	> 12.00
9	Ploughing	0.380	0.360	0.280	0.791	0.036	0,380 (x)	6.31	> 12.00
	Harrowing	0.370	0.350	0.190	0.738	0.196	0,370 (x)	6.52	> 12.00
10	Ploughing	0.412	0.604	0.541	1.16	0.072	0,604 (y)	2.35	> 12.00
	Harrowing	0.753	1.16	1.08	2.21	0.092	1,16 (y)	0.42	4.02

In the remaining operations a_v varies between the daily action value (0.5 ms^{-2}) the limit value (1.15 ms^{-2}). In particular, observing the data of the tractors No. 1, as the chopping and the distribution of chemicals do not require high traction performances and are usually made on more even surfaces, low values of the horizontal components, a_{wx} and a_{wy}, can be noticed, as the vertical, a_{wz}, resulted the most significant component and has been used in the calculation of the two exposure times that, at any rate, have been the highest together with the exposure times of the tractor No. 9. This was equipped with two special devices: an hydraulic self-levelling system of the cab and an hydraulic suspension at the front axle. The latter device is automatically excluded by locking the differential and it has not been used in the ploughing and harrowing tests, as the cab self-levelling system normally worked. The most severe solicitations occurred along the x-axis (travel direction), as the vertical component resulted the lowest testifying of a good performance of the seat suspension.

Considering the safety time, the values obtained from all the other tractors, would allow to work two to three hours a day. The things substantially change referring to the limit time, because the resulting exposure times always are higher than 8 hours except for the tractor No. 10 in harrowing.

Conclusions

From the test results of the present paper emerged the great complexity of the agricultural work conditions from the point of view of the exposure to the vibrations, confirming the data observed in previous experiences. In this context it is often very difficult to operate a generalization, applying models developed for different operative situations.

Basing on the correctness of the methodological approach aimed at measuring the fundamental parameters, the discussion should involve the determination of the exposure times. Notwithstanding the transformations and the undoubted evolution of the agricultural work, it still keeps characteristics different from any other sector, that necessarily are reflected on the aspects of worker's safety and health.

The main peculiarity of agricultural work from the point of view of the exposure to vibrations is represented by the high variability of their level as a consequence of environmental factors (seasonality of the productions, meteorology, soil characteristics, etc.) and management choices (involving, for instance, the production lines, the organization of the work, the kinds of machines etc). This variability is referred both to the year and to the single working day and often causes the occurrence of heavy working loads in brief periods (in the year and in day) in which the levels of vibrations, determined by different equipments, assume different values and characteristics.

It is difficult to apply a model developed for evaluating the exposition to vibration in industrial working environments to such a situation. The combined effects of the vibration level and of the exposure time should be reconsidered referring to the above mentioned factors typical of agricultural works and, in addition, to the different kinds of agricultural worker: a farmer will undergo minor solicitations, for instance in tilling its fields in a few days, than a farm-contractor that, in order to maximize its profits, has to make the same operations in large extensions for longer periods.

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