Whole Body Vibrations of Tractor Driver in Citrus Orchard

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Abstract

This paper reports the results of the first analyses carried out to evaluate the vibration level the tractor driver is subject to during pesticide application in a citrus orchard. The measurements were carried out during ordinary working conditions by using a triaxial accelerometer placed on the seat of a 4-wheel (all with the same diameter) drive tractor. The sprayer used was a trailed conventional one with hydraulic pulverisation and axial fan.

The vibration exposure was computed globally and for each working phase (transfer, spraying, turnings, transients, etc.). The main results showed that, with reference to the whole working cycle, the weighted root mean square (RMS) values of acceleration (around 0.6 m/s^2), were always slightly higher than the daily exposure action value fixed by the 2002/44/EC directive; among the different working phases, the highest values of acceleration occurred during transfers from and by the farm centre, where the tank of the sprayer was filled, due the higher forward speed. Finally, the FFT analysis showed the main harmonic between 35 and 37 Hz, corresponding to the engine speed. Furthermore, other lower frequency harmonics, at around 2–3 Hz, were present, due to the forward movement of the tractor.

Keywords: safety, comfort, pesticide applications

Introduction

Vibration exposure of agricultural workers is one of the most important topic concerning safety and comfort (Pessina and Bonalume, 2009). The problem can be exacerbated by the increase in mechanisation level of many activities recognised in the last decades. This is particularly true for tractor drivers, whose exposure can be time prolonged. Exposure takes place mainly through the seat and is related to several factors, among which agricultural activity, forward speed, ground profile, engine speed, seat features, can be cited (Butkta *et al.*, 1998; Cutini and Bisaglia, 2007; Giunchi *et al.*, 2008).

Several researches have been carried out to measure the levels of whole body vibration to which tractor drivers are exposed during farm activities (Scarlett *et al.*, 2007; Pessina and Bonalume, 2009). These Authors report high levels of exposure during transfers and when old tractors are used, whose seats are often deteriorated or without an efficient suspension system.

Even if the only documented relationship between whole body vibration exposure and medical pathologies is related to the backache and the trauma on the rachis, several other consequences (muscular pain, alteration of the gastro-enteric apparatus, the peripheral venous system, the reproductive female apparatus and the cochleovestibular system) are related to the exposition to specific vibration frequencies, even if these would be also provoked by other causes (Enama, 2005; Ispesl, 2001). For example, troubles of the cervical-brachialis district could be also provoked by repetitive movements to control the machine.

Since the vibration risk is increasing in Europe both for the safety consequence of

The Authors equally contributed to the present study.

workers and the social costs, in the last 15 years the regulatory activity has produced several European Directives to improve the safety characteristics of the machines. The main Directives were accepted in Italy by means of the D.P.R. (Presidential Decree) no. 459 of 24th July 1996 and of the government decree no. 187 of 19th August 2005. The first, known as "Machine Directive", obliges the machinery-maker to reduce at the source the risks for the workers, also from the point of view of vibratory phenomena; therefore it stimulates the designing of new machinery taking into account the reduction of the vibration level connected with its functioning. The second government decree implements in Italy the Directive 2002/44/EC, that establishes the limits to the daily vibration exposure for the workers. Furthermore, from July 2010, it prohibits the use of machinery that does not allow the observance of these limits; only for the agro-forestry machinery there is 4 years' extension. The government decree no. 81 of 9th April 2008 completes the main regulatory framework on safety workers. It obliges employers to carry out a risk evaluation for all the work activities and to take appropriate measures for accident prevention and workers' health safeguard.

Objective of this study is the measurement of the whole body vibrations transmitted to the tractor driver during pesticide application in a citrus orchard when using a four wheeled isodiametric tractor and a conventional air assisted sprayer. This is only the first approach and other measurements will be carried out to cover all the activities in citrus orchards and to analyse other operative conditions.

Materials and Methods

Operative conditions

To carry out the pesticide application, a trailed conventional sprayer with 1500 L main tank, hydraulic pulverisation, and arc-shaped spray boom equipped with 14 nozzles was used (Figure 1). The sprayer was also equipped with an axial fan and was run by a 55 kW four wheel drive isodiametric tractor. The engine speed was 2200 rpm and the average forward velocity was 1.21 m/s. The trials were carried out during pesticide application in a citrus orchard with tree lay-out of 4 m × 6 m. Any row was 270 m long and the headlands were large enough to allow the fast turning of the machines used for cultivations. Two farm roads, around 6 m large, intersected the orchard that, therefore, was divided into three sectors. The driver stopped spraying during the turning and in correspondence of only one transversal farm road (Figure 2).

Figure 1. Tractor and sprayer used.

Figure 2. The transversal farm road.

Measurement equipment

Vibration measurements were carried out by using an AP Tech triaxial seat transducer, designed in accordance with the criteria stated in the European Standard EN 1032:1996 and intended for measurement of whole body vibration according to the UNI EN ISO 2631-1997. The device was fixed to the seat with adhesive tape (Figure 3) and the accelerometer was oriented in accordance with the ISO 2631 regulation (Figure 4).

Figure 3. The triaxial seat transducer.

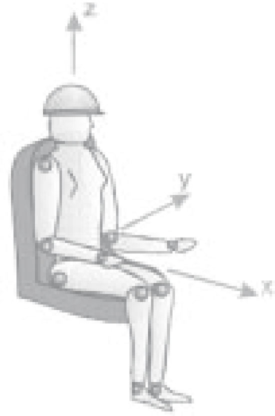

Figure 4. The reference coordinate system adopted.

The vibration signals were recorded by using a PC-based acquisition system made up of a four-channel USB-II data acquisition unit (dB4), a notebook and dedicated software dBFA Suite software (01 dB-Metravib). The software allows for several post-processing analyses, among which narrow band analysis (FFT), 1/3 octave analysis, and frequency weighting according to the ISO 2631 regulation.

Experimental conditions and data analysis

The measurement time covered the whole working cycle, including spraying and transfers from the field to the supplying point and vice versa, so to obtain the global value of exposition to the vibrations for the driver. Four replicates were carried out and the signals were recorded with sampling frequency of 1600 Hz.

Successively the signals were analysed in laboratory by computing narrow band (FFT) and third octave analysis. They were analysed in the range 1–104 Hz (third of octave bands from 1 to 80 Hz) by applying the FFT and the 1/3 octave analysis and by computing the frequency weighted accelerations for each axis (a_{wx}, a_{wy}, and a_{wz}) and then the highest acceleration value a_w:

$$a_w = max(1.4 \cdot a_{wx};\ 1.4 \cdot a_{wy};\ a_{wz}),$$

from which the daily vibration exposure values, A(8), standardized to an 8-hour reference period, were obtained:

$$A(8) = a_w \sqrt{T / T_0}\ ,$$

being T_0 = 8 hours and T the total exposure time associated with a_w.

The A(8) values were compared with the *Daily Exposure Action Value* of 0.5 m/s^2 and the *Daily Exposure Limit Value* of 1.15 m/s^2 established by the EU 2002/44/EC directive, implemented in Italy with the government decree 187/2005.

As during the trials the starting times of each working phase (spraying, turning and transfers) were recorded with a chronometer, the respective daily exposure values were calculated by analysing the correspondent signal extrapolated from the whole signal (Figure 5). Graphical representations were carried out by using the open source software R.

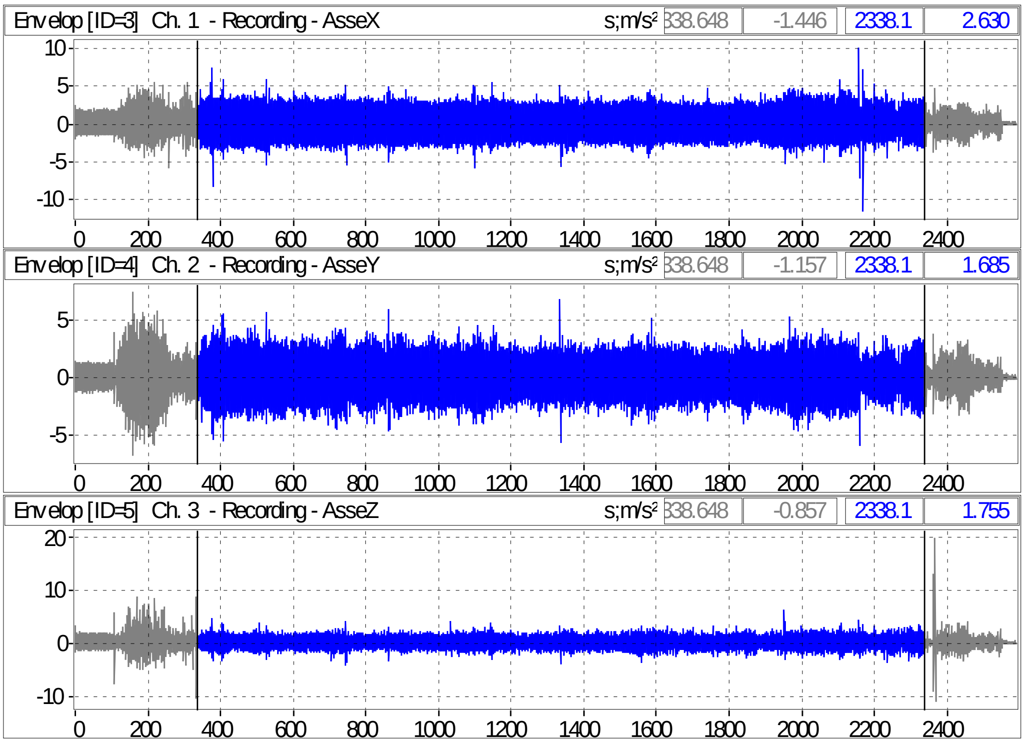

Figure 5. Signal selection to analyse only the spraying activity.

Results

By analysing the times recorded during the trials, it was found that it was hourly need to fill the main tank of the sprayer. This activity required around 10 minutes so, considering a working day of 7 hours, the effective exposure time was about 6 hours. Furthermore, it was calculated that the incidence of the transfer times on the total time (spraying and transfer time) was around 20 percent.

With reference to the signal analysis, taking into account the recorded times, in Figure 5 it is possible to note peaks in correspondence of the turning phase, when the driver restarts spraying. Nevertheless, their intensities are not very different with respect to the stationary signal and the time lapse between two consecutive peaks is so large that the vibration dose value (VDV) computation is not necessary.

From each signal elaborated, the weighted acceleration values were computed via the 1/3 octave analysis. It was considered both the whole signal and sub-intervals to distinguish working phases: spraying and transfers. Consequently several replications, but with different duration, were obtained and the average value for each working phase was computed as weighted mean, taking as weight the duration of the analysed signal.

Successively, taking into account the daily exposure times, the A(8) values were obtained. In all cases the A(8) values were under the limits imposed by the regulations (Table 1) as daily exposure action value. It must be observed that these results are a consequence of the daily exposure time less than 8 hours. In fact, the maximum weighted acceleration values, especially the *z*-component during the transfer phase, when the forward speed was higher, were greater than 0.5 m/s^2 (Figure 6). Furthermore, the weighted acceleration values in each replication showed lower data dispersion for *x*- and *y*-components, pointing to constant exposure intensity. Then the working conditions must be continually monitored because of the proximity to the daily exposure action value: different ground profile or different incidence of the transfer phase could cause an increase in the exposure values. Alternatively, it could be necessary to change the seat because of its wear (Figure 3), but the installation of new model seat, able to damp dawn vibrations, should be evaluated with the maker.

Table 1. Daily vibration exposure value for different working phases.

Working phase	A(8), m/s^2
Spraying	0.39
Transfer	0.29
Whole	0.45

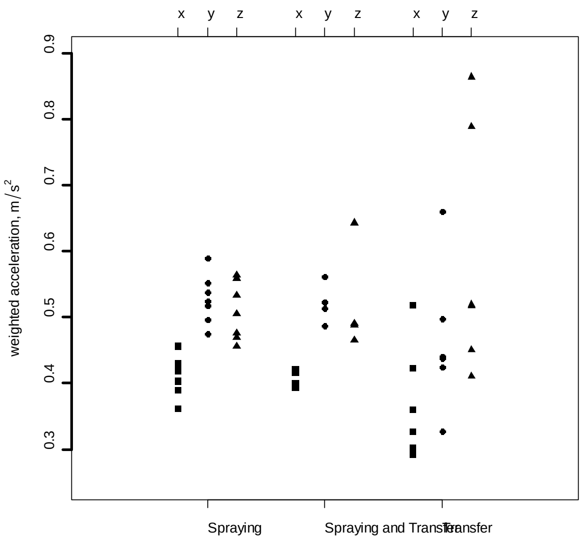

Figure 6. Weighted acceleration values computed in each replication.

Looking at the weighted acceleration components (Figure 6), it is possible to observe that the lowest vibrations were always those along the longitudinal axis (*x*-direction), while the other components showed different trends for the different working phases. In fact, during the transfer phase there were the highest weighted acceleration values along the vertical axis (*z*-direction). This is due to the higher forward speed, especially during the transfer to come back to the supplying point. Instead, during the spraying phase and the whole working cycle, the components along the transversal and vertical axis are comparable. There was a reduction in the *z*-component and an increase in the *y*-component. These variations are explicable respectively with the lower forward speed and the higher engine speed of the tractor during the spraying.

FFT analysis

Figure 7 reports an example of FFT spectra in the range 0–104 Hz for the three directions during the transfer phase. Similar spectra were found for all the other measures in the same conditions. The spectra show appreciable harmonics along all the three directions in the range 2–4 Hz due to the ground profile. Other harmonics are present at 7 Hz (*y*-direction) and 15 Hz (*x*-direction), probably due to the high forward speed. However, the main harmonics are found between 29 and 34 Hz, corresponding to the engine speed. At last, several harmonics between 50 and 72 Hz are present mainly along the longitudinal axis (*x*-direction). These could be caused by the empty tank of the sprayer towed by the tractor.

The other FFT spectra obtained by analysing the spraying phase or the whole working activity show some little differences:

- the harmonics at 7 and 15 Hz and those in the range 50–72 Hz were no longer present, confirming the influence of the high forward speed for the former and the effect of the empty tank of the sprayer for the latter;

- the main harmonic now took place between 35 and 37 Hz, corresponding to the engine speed during the working phase.

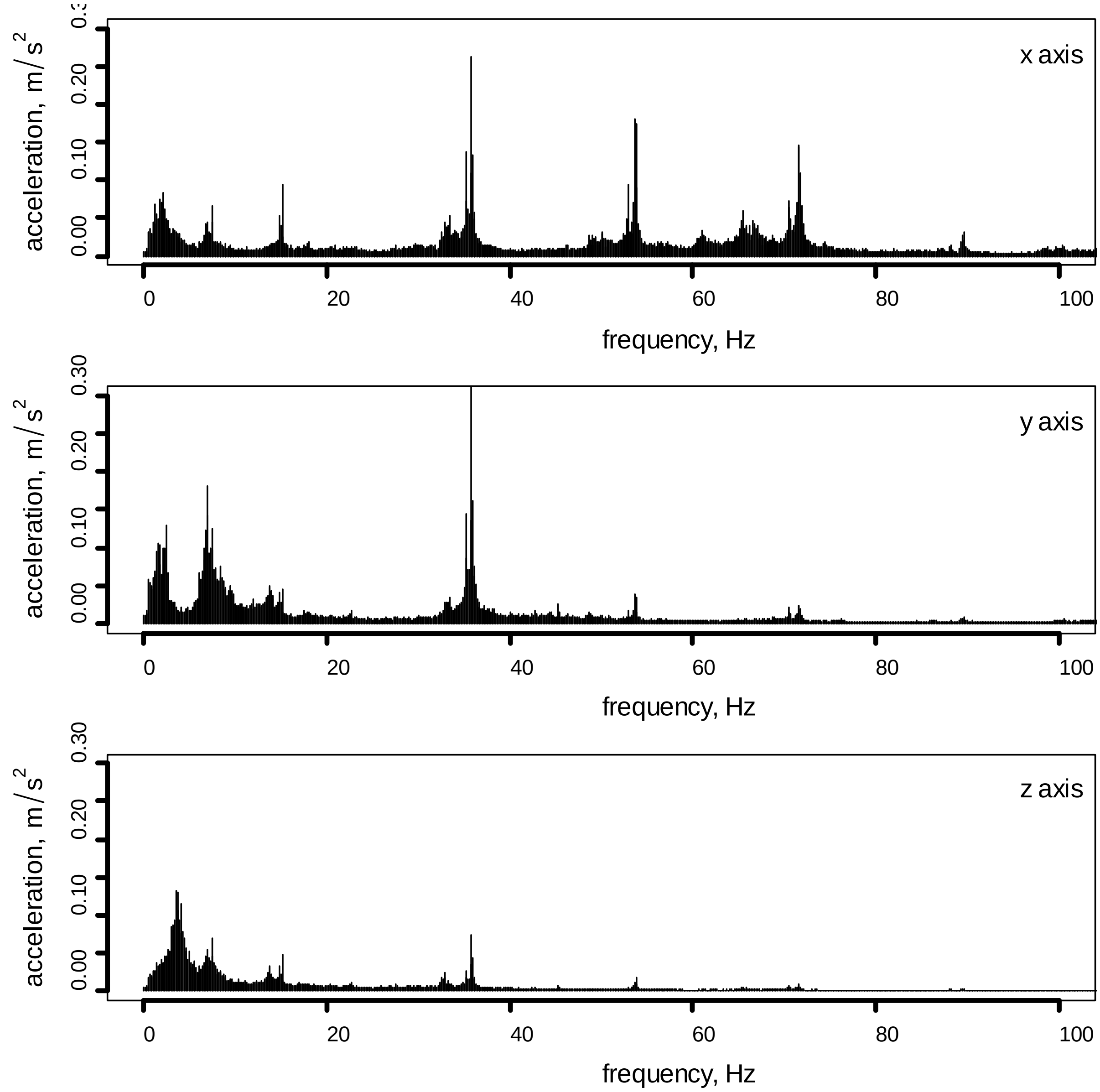

Figure 7. Examples of FFT spectra.

Conclusions

The study, even if preliminary, allows for some considerations:

- The procedure adopted proved to be effective in assessing the daily vibration exposure of operators during pesticide distribution in citrus orchards. By timing the agricultural activities and by recording the whole signal, it is possible to evaluate the influence of the several working phases on the daily acceleration values. The methodology can be extended to other agricultural activities concerning citrus cultivation so to assess the effective risk of vibration for operators.

- With reference to the situation analysed, the measured daily exposure values A(8) were under, but near, the limits established by the current regulation, so in different working conditions (different incidence of the transfer times with respect to the whole operating cycle, different ground profiles, machine features, forward speeds, etc.), it is possible to get an increase in the exposure values and then appropriate cautions should be taken into consideration.
- Given the previous observations, further studies are necessary to investigate different working conditions so to prepare a complete database useful to assess the real risk of operator's vibration exposure in citrus fruit sector.

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