

Vibrations Produced by Electric Shakers for Olive Harvesting

Cerruto E., Manetto G., Schillaci G.

Dipartimento di Ingegneria Agraria (DIA), Via Santa. Sofia, 100 – 95123 Catania, Italy

Tel. +39 0957147514, Fax +39 0957147600

ecerruto@unict.it; gmanetto@unict.i; gschilla@unict.it

Abstract

The paper reports the results of some experimental tests aimed at evaluating the effects of several manual electric shakers for olive harvesting on the vibrations transmitted to the hand-arm system. Three harvesting heads, different for number and arrangement of operating tools and oscillating system, each applied to three types of bars, different for material (carbon fibres and aluminium), diameter (35 and 40 mm) and length (2010 and 2210 mm), were considered. The vibrations were measured in two points, next to the hand positions on the bar in working conditions, at varying the bar inclinations (vertical, inclined at about 45 degrees, and horizontal). To smooth the influence of external factors, the machines were idle operated by the same person.

The main results show that global accelerations are quite high (about 20 m/s²) and comparable with those measured when using mechanic or pneumatic machines, that the oscillating mechanism of the harvesting head affect the accelerations, that carbon fibre bar provide a significant reduction in accelerations with respect to the aluminium (16.3 vs. 21.2 m/s²), that the bar inclination does not affect the vibration level, and that the accelerations on the bar are greater than those on the handgrip (21 vs. 16 m/s²).

Keywords: safety, hand-arm system, facilitating machines

Introduction

Drupe harvesting is the most expensive phase of the olive production, so the use of handheld vibrating machines is very widespread to increase productivity, mainly when full mechanisation is not possible (Famiani *et al.*, 2008). Unfortunately, the increase in the mechanization level introduces additional sources of risk for operators, as noise, vibrations, and fatigue due to the weight of the shakers (Iannicelli and Ragni, 1994; Blandini *et al.*, 1997; Deboli *et al.*, 2008; Pascuzzi *et al.*, 2008).

The effects of vibrations on the hand arm system can lead to the well-known Raynaud syndrome, a disease which demands attention from all medical personnel (Chetter *et al.*, 1998). The byodynamic response of the hand-arm system is affected by several factors, among which acceleration, vibration direction, frequency, posture, grip force, operating tool, and handle sizes can be cited (Dewangan and Tewari, 2008; Aldien *et al.*, 2006; Monarca *et al.*, 2003; Buström, 1997). Moreover, some of these factors are correlated with the effectiveness of anti-vibrating tools (Dong *et al.*, 2005), which can reduce strongly the acceleration transmitted, so reducing in the same time work stress (Tewari and Dewangan, 2009).

Beside the use of anti-vibratory tools, the best protection against vibrations lies in adopting working practices aimed at prevention. Employers should ensure that workers at risk of developing hand-arm vibration syndrome receive adequate health education. This aspect, unlike the industrial environment, is often underestimated among agricultural farmers, due to

the typical variability of the working conditions. As an example, the use of handheld shakers for drupe harvesting is limited in time, so the harvest capacity is the main characteristic that influences the purchase. Even so, machines powered by electric motors have been marketed for some years, mainly to reduce noise and increase operator’s comfort (Biocca *et al.*, 2008), so trying to respect the limits imposed by the recent regulations (government decree of August 19, 2005, no. 187; government decree of April 9, 2008, no. 81). Their development has involved changes in shape and dynamics of the harvesting system, as well as in the material for their construction (introduction of carbon fibres to reduce weight). These variations can affect the accelerations transmitted to the workers during their use, so different levels of vibration should be expected.

This research aims to evaluate the vibrations transmitted to the hand-arm system when using electric shakers at varying material and diameter of the bar, configuration of the harvesting head, and inclination of the bar during the use. A first study was proposed in Cerruto *et al.*, 2009a and Cerruto *et al.*, 2009b, which is here developed more in detail by increasing number of replicates and by performing a carefully frequency analysis.

Materials and Methods

Electric shakers

Experimental tests were carried out by using electric shakers powered by 12 V d.c. motors. Three harvesting heads and three bars were tested, so to give rise to a full factorial design. The three harvesting heads (Figure 1) are different for number and arrangement of the operating tools, as well as for direction of the oscillations. The first (H1) and the second (H2) have 8 operating tools, while the third (H3) 12. All operating tools are in carbon fibres and are of the same size (diameter = 5 mm, length= 370 mm). In H1 and H2 the operating tools are fixed to a 36-centimetre bar orthogonal to the motor shaft, while in H3 the bar is parallel to the motor shaft, so the oscillating planes are orthogonal. Number and arrangement of the operating tools can be modified, so the three harvesting heads can be assembled by the user according to his/her needs. The main features of the harvesting heads are reported in Table 1.



Figure 1. The three harvesting heads (H1, H2, and H3 from left to right).

Table 1. Harvesting head and bar features.

Harvesting heads			Bars				
	Operating tools, no.	Mass, kg		Material	Diameter, mm	Length, mm	Mass, kg
H1	8	1.545	B1	Aluminium	35	2010	1.356
H2	8	1.545	B2	Carbon fibre	40	2210	1.342
H3	12	1.365	B3	Aluminium	40	2210	1.416

The three bars tested are different for material, diameter, and length, as reported in the same Table 1. By comparing bars B2 and B3, the effect of the material (aluminium and carbon fibres) on the vibrations can be evaluated, while by comparing bars B1 and B3, the effects of diameter (35 and 40 mm) and length (2010 and 2210 mm) can be evaluated. The thickness of the material (2 mm) is the same for all the bars.

The electric motor (maximum power of 900 W and rotating speed of around 6000 rpm, fixed by a electronic card) is the same for all the three harvesting heads. It is feed by means of an external 12 V battery and the electric cable is lodged inside the bar, from which it emerges near the handgrip equipped whit the activation switch. The motor shaft is connected to a box that, with the same gear ratio of 10:58, gets the operating tools moving with frequency of around 18 Hz.

Measurement equipment

Vibrations measurements were carried out by using three mono axial accelerometers DJB, model A/123/S, screwed on to the mutually orthogonal faces of a small cube tied to the bar by a metallic clamp (Figure 2). The reference axes were selected according to the basicentric coordinate system defined by the UNI EN ISO 5349-1:2004 regulation (Figure 3).

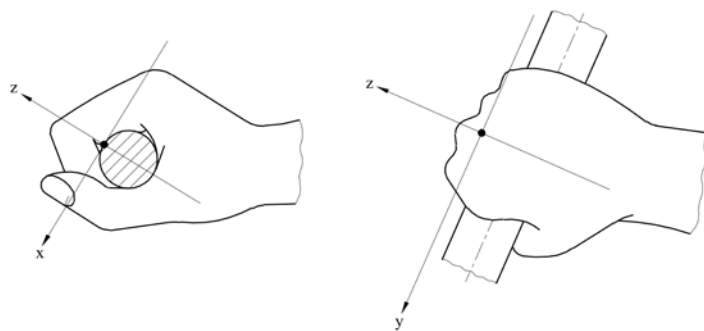
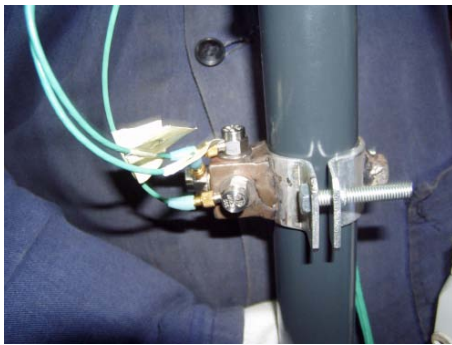


Figure 2. Positioning of the accelerometers on the bar. **Figure 3. Reference axes for vibration measurement.**

The accelerometer signals were amplified by means of three amplifiers MESA, model C24, and then recorded on digital tapes by means of a four channel digital audio tape (DAT) recorder. Subsequently they were analysed by using a PC based analysis system made up of a four-channel USB-II data acquisition unit (dB4), a PC, and the 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 5349 regulation.

Experimental design and data analysis

The experimental activity was aimed at evaluating the influence of harvesting head, bar features (material and geometry), and bar inclination, on the vibrations transmitted to the hand-arm system. To this end, a full factorial experimental design with three factors was developed: harvesting head (three levels: H1, H2, and H3), bar type (three levels: B1, B2, and B3), and bar inclination (three levels: 0° (horizontal), 45° (inclined), and 90° (vertical)). Moreover, the accelerometers were placed, at different times, in two points next to the positions of the hands in ordinary working conditions, as reported in Figure 4.

Fifty-four measurement sessions were carried out (3 harvesting heads \times 3 bars \times 3 inclinations \times 2 measurement points), each lasting about 5 minutes. To reduce the influence of

external factors, during the tests all the shakers were idle operated by the same person. To simulate some replications, from each measurement session 4 samples of 1 minute were extracted. They were analysed in the range 5.6–1400 Hz (third of octave bands from 6.3 to 1250 Hz) by applying the FFT and the 1/3 octave analysis and by computing the frequency weighted accelerations for each axis (a_{hwx} , a_{hwy} , and a_{hwz}) and then the global acceleration a_{hw} :

$$a_{hw} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2},$$

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

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

being $T_0 = 8$ hours and T the total exposure time associated with a_{hw} .

The A(8) values were compared with the *Daily Exposure Action Value* of 2.5 m/s^2 and the *Daily Exposure Limit Value* of 5.0 m/s^2 established by the EU 2002/44/EC directive, implemented in Italy with the government decree 187/2005.

All acceleration data were statistically analysed to detect differences related to harvesting heads and/or to bar type and/or bar inclination. Statistical analyses and graphical representations were carried out by using the open source software R.

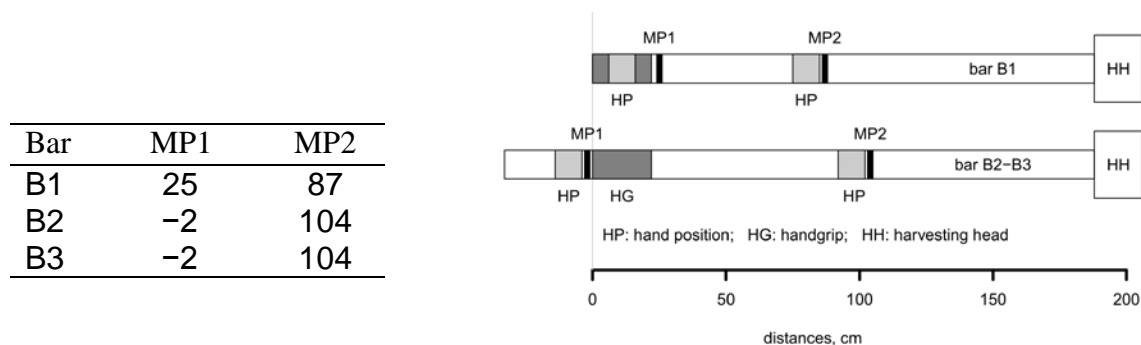


Figure 4. Measurement point (MP) position: distances in centimetres.

Results and Discussions

Global weighted acceleration

Weighted acceleration values were computed via the 1/3 octave analysis. Comparing global values for each harvesting head, bar type, bar inclination and measurement point, Figure 5 was obtained. It shows global weighted acceleration values quite high (approximately 20 m/s^2), meaning the vibration level is mainly affected by the kinematic system rather than the power source (electric, mechanic or pneumatic). Moreover, it suggests some differences, to be validated from the statistical point of view, among bars, harvesting heads, and measurement points, but not among inclinations. In fact, the Kruskal-Wallis test (being samples pseudo-replicates, data were analysed by means of non parametric tests) produced the results reported in Table 2, which confirms first of all the lower vibrations for the carbon fibre bar with respect to the aluminium one with the same diameter (B2 vs. B3), as well as no differences between the two aluminium bars (B1 vs. B3). These results strengthen ($p\text{-level} = 1.372e-5$) those presented in Cerruto 2009b, due to the higher number of samples extracted from each measurement session. The differences among the harvesting heads are significant too. The highest vibrations are produced by H1, whose operating tools are spatially misaligned, the lowest by H3, which oscillates around the axis to which the operating tools are connected. This confirm that the vibration level can be reduced mainly acting on the

mechanism that moves the operating tools.

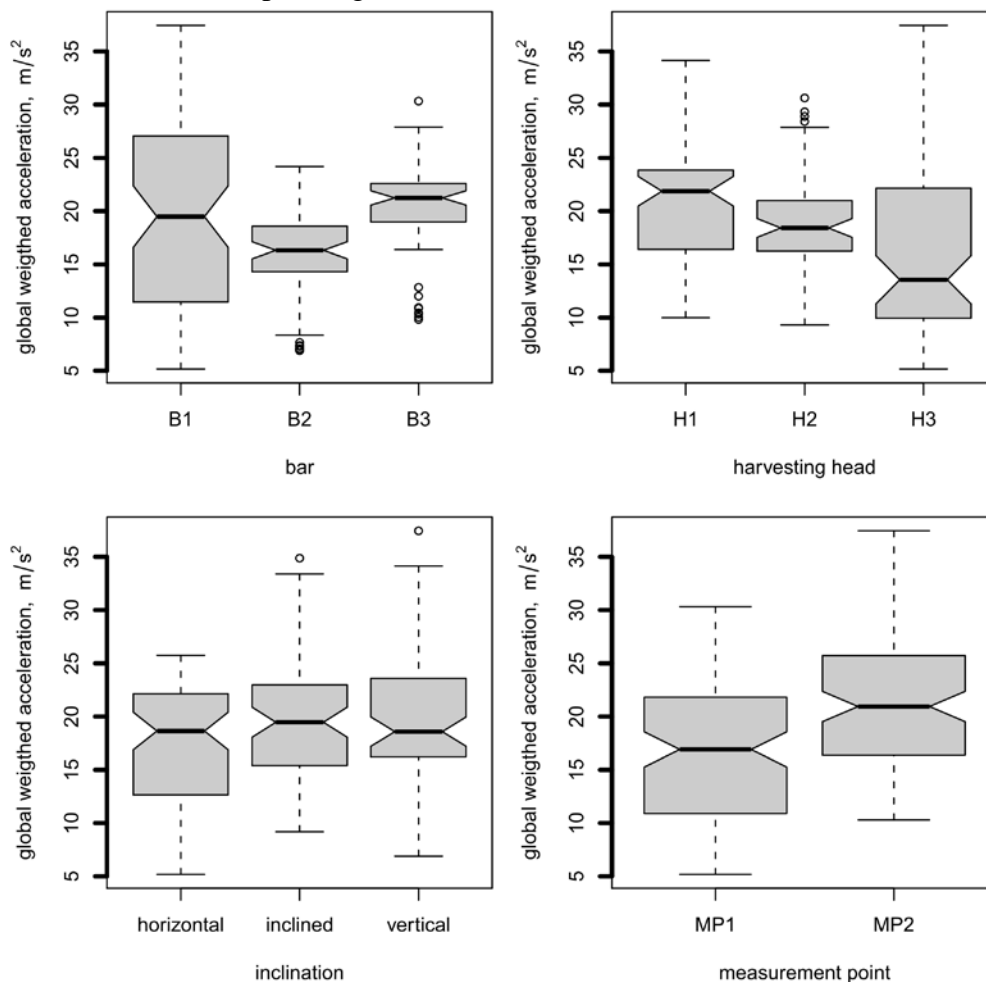


Figure 5. Global weighted accelerations.

Table 2. Median values (m/s²) of global weighted acceleration (median separation by Kruskal-Wallis test at p=0.05).

Bars	Harvesting heads	Inclinations	Measurement points
B1	21.9 ^a	Vertical	MP1
B2	18.4 ^b	Inclined	MP2
B3	13.6 ^b	Horizontal	

The differences among the bar inclinations are negligible (from 18.6 to 19.5 m/s²), whereas are significant those between the two measurement points. On average, the hand which holds the bar (MP2) is more exposed than that near the handgrip (MP1). Probably the lower vibration measured near the handgrip is due to its greater distance from the source of vibration (the harvesting head).

These accelerations are much higher than the daily limit and action values established by the European directive 2002/44/CE. By considering as an example the range 13.6–21.9 m/s² inside which fall the median values of the three heads, the daily limit exposure time should range from 0.1 up to 0.3 h and the daily action exposure time should range from 0.4 to 1.1 h (Figure 6): all times are clearly incompatible with the length of a standard work-day in agriculture, so the use of appropriate personal protection equipment should be taken into

consideration.

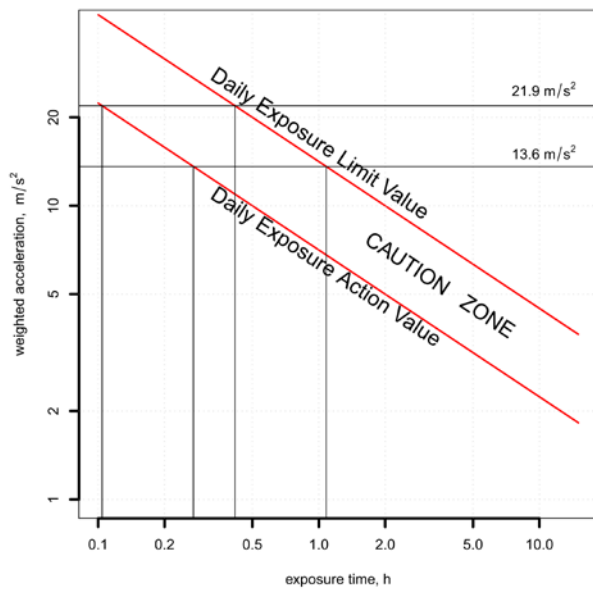


Figure 6. Daily exposure values.

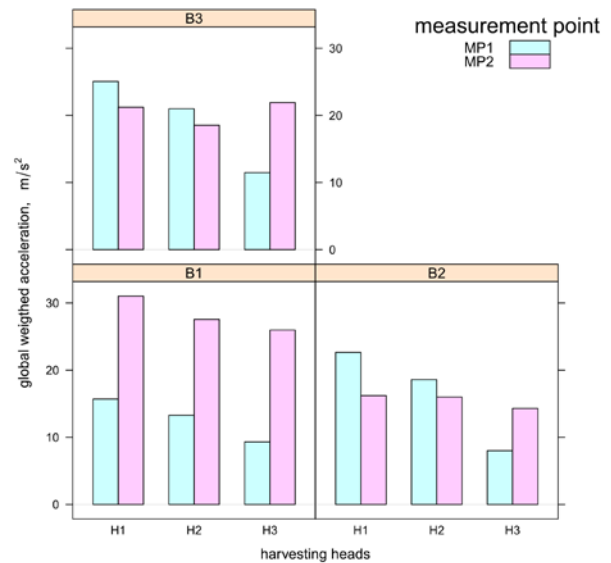


Figure 7. Global weighted accelerations: interactions among bars, harvesting heads and measurement points.

The interactions among bars, harvesting heads and measurement points are reported in Figure 7. It shows that the higher values of acceleration measured on the bar (MP2) are mainly due to the bar B1. As this behaviour is present with all the harvesting heads, most likely it is the lower diameter that makes bar more flexible and than more subject to vibration in its central part.

Acceleration components

The weighted acceleration components are reported in Figure 8. The lowest vibrations were always those along the bar axis (y direction), whose values ranged from 0.93 up to 6.56 m/s^2 . For each harvesting heads there was always a dominant component: z direction for H1 and H2, ranging from 8.29 to 33.20 m/s^2 , and x direction for H3, ranging from 2.71 to 36.40 m/s^2 . This difference in the direction of greater vibration is due to the different plane of oscillation of the harvesting heads H1 and H2 with respect H3.

FFT analysis

Figure 9 reports some examples of FFT spectra in the range 0–250 Hz for the three directions. Similar spectra were found for all the other measures. They show the first harmonic at about 14.6 Hz for bar B1 and at about 17.0 Hz for bars B2 and B3. This harmonic corresponds to the motor speed: in fact, taking into account the gear ratio of 10:58, the motor speed results 5080 rpm for bar B1 and 5920 for bars B2 and B3. As the motor speed is fixed by the electronic circuitry placed inside the handgrip of each bar, it follows that the electronic card was running differently for bar B1.

Finally, the spectra show some other appreciable harmonics in the range 100–200 Hz, mainly in x and z directions, but their contribution to the global acceleration is negligible due the weighing filter. Analogous results can deduced from the 1/3 octave spectra, that show the greatest weighted RMS values in the 16 and 31.5-hertz bands.

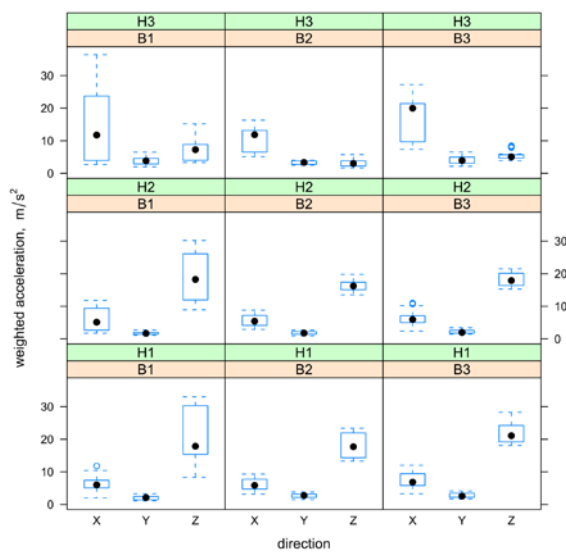


Figure 8. Weighted acceleration components for bars and harvesting heads.

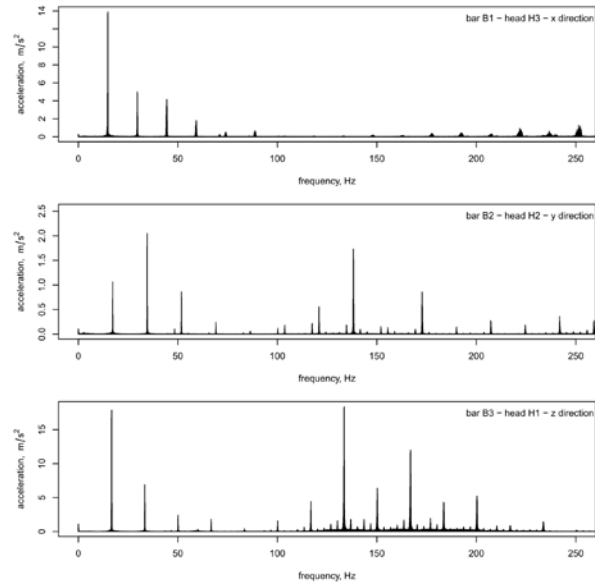


Figure 9. Examples of FFT spectra.

Conclusions

The study allows for the following considerations, susceptible to be integrated by further investigations:

- The measurement procedure proved effective in ascertaining the vibrational level of the shakers. Comparisons among different machinery should be carried out in standard conditions, keeping constant all external factors (operator's influence, operating modes, load parameters). The effective daily operator's exposure should be measured during harvesting tests, as an influence of the tree canopies on the vibrations transmitted to the hand-arm system is expected.
- Global weighted accelerations are quite high for all the shakers applied to any bar: this means that the vibration level is mainly affected by the kinematic system that gets moving the operating tools rather than the power source. Probably this is the key aspect to be investigated to reduce the vibrations at source. Actually, electric systems increase the operator's comfort by reducing weight and noise with respect to the mechanic or pneumatic systems.
- Carbon fibre bars have a positive effect in reducing the vibrations transmitted to the hand-arm system with respect to the aluminium ones. This has also a positive effect on the comfort of the operators as reduce the global weight of the machinery.
- The inclination of the bar during the use of the shaker has little effect on the global weighted acceleration, so recommendations to operators are unnecessary from this point of view.

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