Risk Assessment of Hand-Arm Vibration in Different Types of Portable Shakers for Olives Harvesting

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Abstract

The aim of this study was to assess the level of exposure to hand-arm vibration of the operators using portable shakers. Some of the models commonly used were evaluated and correlated with the work capacity evaluated by field tests. Three different models of portable shaker with hook were compared. The tests were carried out in year 2009 both in laboratory and in the field. The field tests aimed to determine the work capacity of the three shakers; the laboratory tests were carried out according to ISO 5349-2 to assess the level of exposure to hand-arm vibration of the operators.

The results obtained from the laboratory tests allow to draw interesting comments on the evaluation of human exposure to hand-arm transmitted vibration highlighting how in some cases, the daily limit of 5 m/s^2 under the Decree 81/2008 was exceeded.

Keywords: harvest, olive, shaker, vibrations

Introduction

In olive growing the mechanization of harvest is very important both to reduce the costs of production and to assure the oil quality because the manual harvest does not allow to operate at the right time and also need a long period to be completed.

The use of portable shakers, that are spreading more than others typologies, can give a solution to the problem. The work capacity is from two to three time higher than the manual harvest; these shakers can be used also in farms whose orchards are little suitable for the mechanization because of steep slopes, training system not allowing the machines to pass, soils having high moisture content.

However, the use of such equipment may involve risk of exposure to hand-transmitted vibration.

The reference standard, UNI EN ISO 5349-1:2004 gives the characterization of the vibration transmitted to the hand and a guide to the health effects.

Excessive and daily exposure to hand-arm vibration can disturb the circulatory system and neurological and locomotor apparatus of the upper limbs. The combination of vascular, neurological and musculo-skeletal periphery disorders caused by exposure to hand-arm vibration is commonly referred to as "hand-arm vibration syndrome". In exposed workers, vascular and neurological disorders may occur in parallel or independently of each other. Osteoarticular and vascular lesions of the upper limbs caused by hand-arm vibration are also considered as occupational diseases for compensation in many countries.

Workers exposed to hand-arm vibration may present episodes of paleness in the fingers. These episodes are usually triggered by exposure to cold; it is a vascular disorder due to a temporary arrest of blood circulation in the fingers (Raynaud's phenomenon).
Other effects resulting from exposure to hand-arm vibration are neurological, such as tingling and numbness in fingers and hands. Persisting exposure, these symptoms tend to worsen and can interfere with the ability to work and activities of daily living. Clinical examination may show a reduction in tactile and thermal sensitivity and a decrease in manual dexterity, as well as entrapment neuropathies of nerves like carpal tunnel syndrome (CTS) due to compression of the median nerve in the passage along an anatomical tunnel in the wrist.
With reference to muscle disorders, workers with prolonged exposure to hand-arm vibration can suffer muscle weakness, pain in hands and arms and a decrease in muscle strength. It was also found that the vibration exposure is associated with a reduction in grip strength on the tool handle.
The Decree 81/2008 defines the limit of daily exposure to a standardized reference period of 8 hours, at 5 m/s^2.
The aim of this study was to assess the level of exposure to hand-arm vibration of the operators using portable shakers. Some of the models commonly used were evaluated and correlated with the work capacity evaluated by field tests.

Materials and methods

Three different models of portable shaker with hook were compared. They consist of a bar having an hook at the end which transmits the vibrations induced by the machine to the branch.

Table 1. Characteristics of the investigated portable shakers

	A	**B**	**C**
	Vibrotek TK 650	**Cifarelli SC 800**	**Valgarden S57S**
Engine	Vip 52 2004	Cifarelli C5	Valgarden
Engine displacement [cm^3]	52	52	56.5
Strokes [n]	2	2	2
Cooling	air	air	air
Tank capacity [l]	1.7	1.7	0.9
Total weight (filled up) [kg]	17.2	18.0	13.3
Length except the bar [mm]	730	1050	400
Bar length/total length ratio	0.73	0.66	-
Length of the bar [mm]	2000	2000	1600
Stroke of the bar [mm]	60.0	60.2	40.1
Hook width [mm]	40.4	40.5	30.2

Two types of shakers were examined (table 1); two of them, Vibrotek TK650 and Cifarelli SC800, respectively named "A" and "B", are provided with an internal combustion engine, with connecting rod-crank system giving the oscillations, that is mounted at the end of the bar near the handle. These machines are generally called "on line shakers". In the other shaker, Valgarden S57S, named "C" the engine is carried on the back of the worker through a frame acting as support; the engine is connected to the vibrating bar through a flexible tube 1.4 m long. This kind of machines is generally called "knapsack shaker".
The tests were carried out in year 2009 both in laboratory and in the field. The field tests aimed to determine the work capacity of the three shakers; the laboratory tests were carried out according to ISO 5349-2 to assess the level of exposure to hand-arm vibration of the operators.
Vibration monitoring presents unique demands on wireless devices, networks and associated components. At present, the one best-suited for condition monitoring applications is 802.11 b/g (often referred to as Wi-Fi).
The measuring chain contains: the digital xyz axis capacitive accelerometer, I2C converter for convert I2C to UART and XBee module for wireless transmission (ZigBee).

Figure 1. Wireless data collection system

We select Freescale MMA7455 triaxial accelerometer as the measurement device, shown in Fig.1 (left). This accelerometer has four different measurement ranges (±1.5*g*, ±2.0*g*, ±4.0*g*, and ±6.0*g*) that can be dynamically set by two input pins. Each range provides different measurement sensitivity. The accelerometer has low power consumption with 2.2V~3.6V and 500μA at the normal condition. It can also be set to a low current inactive mode (*i.e.*, sleep mode) of only 3μA operation current through a SLEEP pin, which further conserves power. The accelerometer continuously records accelerations in all three axes.
The measured data are fed into a microcontroller and sampled via an ADC. We select the Silicon Labs C8051F353 microcontroller with a built-in 24/16 bit ADC in our design. The microcontroller does simple processing on the data and set the working mode of the accelerometer accordingly. Processed data are fed into an IEEE 802.15.4 wireless transceiver and sent to the data logger unit. For our design, the XBee® 802.15.4 radio modem from MaxStream is chosen as the wireless transceiver, as shown in Fig.1 (right). It can operate under transparent mode with a simple connection with a microcontroller. With a chip antenna, it operates up to 30 meters indoor. The transmission range can be further increased to 90 meters by using a whip antenna. The XBee module has a low maximum transmit power of 1mW and a high receiver sensitivity of -92dBm. The front-end of the data logger unit is a wireless XBee transceiver. Upon receiving the measurement data from the wireless interface, the XBee transceiver forwards the data directly to the microcontroller for processing. We choose C8051F344 from Silicon Labs as the microcontroller in the data logger unit. It has convenient USB interface with a flash memory stick or directly to a PC. The processed data then serve as the basis for the calculations and software development involved in the characterization of movements.

Also, there is an initial calibration step in this sketch which assumes the MMA7455 is sitting flat with the z axis pointing up. There are calibration registers in the MMA7455 which need to be set using an interactive procedure so that the x and y axis will initially read zero and the z axis will read 1g. This has to be done each time the chip gets power since the registers are volatile. The 0g offset can be customer calibrated using assigned 0g registers and g-Select which allows for command selection for 3 acceleration ranges (2g/4g/8g).
Field tests were carried out in a farm located in Sciacca, province of Agrigento, Sicily; the variety of the olives was Cerasuola, that is typically suitable to oil production. The plot was 200 m above the sea level, with medium slope and the soil had a middle texture; the trees were about 50 years old, the distance between the rows 7 m x 7 m and the plants "free globe" shaped. The pruning is performed every two years. The mean circumference of the trunk, at the height of 0.5 m from the ground level, was 0.8 m; the mean diameter of the canopy was 5.5 m and the trees 3.8 m tall on average. The free trunk was 1 m tall and the ramification 1.2 m from the ground level.
The harvest was performed by five workers, four of them assigned to the nets and the other to the shaker.
The field tests were repeated three times; the data were statistically analyzed and the mean compared with Duncan's multiple comparison procedure ($p = 0.05$).
Laboratory tests were performed at the maximum engine regime, that is not a standard operative condition but allows to compare the different machines on equal terms on the basis of their intrinsic and design characteristics.
The tests were performed in two ways: keeping the shaker in a horizontal position and maintaining it at an angle of 45 ° to the horizontal, respectively indicated as A_0, B_0, C_0 and A_{45}, B_{45}, C_{45}. The measurement time was 40 s.
The accelerometers position, in compliance with the terms established by UNI EN ISO 5349-1:2004, was determined considering the position of the effective handle of the machine by the operator. Therefore, accelerometers were fixed near the right and left handle of each machine. The fixing was made in a way to ensure the rigid connection to the vibrating surface, using metal clamps.
To quantify vibration exposure, measurements must be taken under representative conditions. Guidelines for measuring and evaluating human exposure and details of different analysis methods for the hand-arm transmitted vibrations are given in ISO 5349-1 and ISO 5349-2. In the ISO 5349 standard recommendations, the most important quantity used to describe the magnitude of the vibrations transmitted to the operator's hands is root-mean square frequency-weighted acceleration expressed in m/s². In addition, it is strongly recommended that for additional purposes frequency spectra should be obtained.
Acceleration values from one-third-octave band analysis can be used to obtain the frequency-weighted acceleration a_{hw}. It shall be obtained using:

$$a_{hw} = \left[\sum_{j=1}^{n} (W_j \cdot a_{wj})^2 \right]^{\frac{1}{2}}$$

where a_{wj} is the acceleration measured in the one-third octave band in m/s², and Wj is the weighting factor for the one-third-octave band.
In accordance with mentioned ISO standards, the three directions of an orthogonal co-ordinate system, in which the vibration accelerations should be measured, were as follows: Z-axis directed along the second metacarpus bone of the hand; X-axis perpendicular to the Z-axis (both these axes are normal to the longitudinal axis of the grip); Y-axis parallel to the

longitudinal axis of the grip. The inclination of the metacarpus bone when the hand grasped the grip was at 45º to the vertical. For practical measurements, the orientation of the coordinate system may be defined with reference to an appropriate basicentric coordinate system originating in vibrating handle gripped by the hand. The evaluation of vibration exposure in accordance with ISO 5349 is based on a quantity that combines all three axes.
The frequency weighted accelerations along the axes and the total acceleration were evaluated both for right and left handle. The values a_{hwx}, a_{hwy} and a_{hwz} were obtained according to the previsions contained in UNI EN ISO 5349-1:2004, as arithmetical average of the ones measured on the same axis (x, y and z) during the three repetitions of each test; the total equivalent accelerations a_{hv} were calculated vector adding the mean a_{hw} values of the three axes:

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

where a_{hwx}, a_{hwy} and a_{hwz} are frequency-weighted acceleration values for the single axes. The vibration exposure depends on the magnitude of the vibration total value and on the duration of the exposure.
Daily exposure duration is the total time for which the hands are exposed to vibrations during the working day. The daily vibration exposure shall be expressed in terms of the 8-hour energy-equivalent acceleration or frequency-weighted vibration total value.
The equivalent vibration total value related to 8 work hours A(8), considering a time of real exposure to vibration (T) of 4 hours, was determined as:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}}$$

where:
T is the total daily exposure to vibration a_{hv};
T_0 is the reference period of 8 hours (28,800 s).
For each working condition, three independent measurements were carried out. Based on these values, the arithmetic mean value of the acceleration values from one-third-octave band analysis and the frequency-weighted acceleration were calculated. Statistical analysis was performed on the measurement data using Statgraphics Centurion by Statpoint inc., USA.

Results

Table 2 shows the values of the work capacity and the results of Duncan's multiple comparison procedure among the means. The values of work capacity show a large variability so that there are statistically significant differences among all the means. It can be noted that the knapsack shakers gave work capacity lower of about 50% than the on line shakers.

Table 2. Results of Duncan's multiple comparison procedure among the means for work capacity

Machine	Work capacity [kg/h]	
	mean	st.dev.
A	220.45 a	0.58
B	346.42 b	2.47
C	124.52 c	0.60

Note: Different letters in the column denote a statistically significant difference at the 95.0% confidence level.

Table 2 shows statistically significant differences among the values of work capacity of the three machines at 95% confidence level.
The shaker having the highest harvest productivity is B with 346.42 kg/h, while the lowest value was obtained by the knapsack shaker C.
In table 3 the values of the frequency weighted accelerations along the axes (a_{hwx}, a_{hwy} and a_{hwz}) and the total acceleration a_{hv} are shown (mean values).

Table 3. Frequency weighted accelerations values along the axes (a_{hwx}, a_{hwy} and a_{hwz}) and total acceleration a_{hv}

Test	Left handle				Right handle			
	a_{hwx} [m/s²]	a_{hwy} [m/s²]	a_{hwz} [m/s²]	a_{hv} [m/s²]	a_{hwx} [m/s²]	a_{hwy} [m/s²]	a_{hwz} [m/s²]	a_{hv} [m/s²]
A_0	4.58	2.97	4.84	7.33	4.34	5.36	4.56	8.28
B_0	5.75	5.17	5.35	9.40	5.12	5.48	3.51	8.29
C_0	6.99	6.61	6.63	11.68	7.25	7.05	7.12	12.37
A_{45}	3.46	3.64	2.67	5.81	3.57	3.91	2.86	6.04
B_{45}	5.54	5.41	4.80	9.11	5.44	5.07	2.57	7.88
C_{45}	6.74	6.56	6.42	11.39	6.65	6.97	6.55	11.65

In table 4 the equivalent vibration total value exposures related to 8 work hours A(8) are reported.

Table 4. Equivalent vibration total value exposure related to 8 work hours A(8) and results of Duncan's multiple comparison procedure among the means

Test	A(8) dx [m/s²]		A(8) sx [m/s²]	
	mean	st.dev.	mean	st.dev.
A_0	5.85 a	0.48	5.18 a	0.22
B_0	5.86 a	0.40	6.65 a	0.13
C_0	8.75 b	0.32	8.26 b	0.11
A_{45}	4.27 a	1.30	4.11 a	1.28
B_{45}	5.57 a	0.24	6.44 a	0.03
C_{45}	8.24 b	0.38	8.05 b	0.24

Note: Different letters in the column denote a statistically significant difference at the 95.0% confidence level.

As regards the A(8) values obtained in the tests, table 4 shows that the highest values were obtained for all machines in the horizontal test, both in the right in the left handle.
From table 4 it comes that the highest A(8) values, higher than 5 m/s^2 which is the daily exposure limit value according to Decree 81/2008, have been obtained in machine C where

the two handles are placed on the vibrating rod. On the contrary, the lowest values were obtained in machine A, in which neither of two handles is placed on the vibrating rod. The A(8) values of the two machines, in fact, show statistically significant differences at 95% confidence level. The data on machine B are intermediate compared to machines A and C as only one handle is placed on the vibrating rod.
In machines A and C the A(8) values obtained in the right and left handles are similar.
In machine B, however, the values of daily exposure to vibration are higher in the left handle, placed on the vibrating rod, with respect to the right, both in the test performed in a horizontal position (12%) than in the test performed at 45° angle (14 %).
The machine B (Cifarelli), who provided the highest work capacity equal to 346 kg/h, recorded A(8) values lower than machine C (Valgarden) with work capacity of 124 kg/h, about 20% in the left handle and about 33% in right handle, in the test performed at 45 °.
The A(8) lowest values, 4.11 m/s^2 obtained in the left handle and 4.27 m/s^2 in the right one, in the test performed at 45° angle, were recorded by machine A (Vibrotek) whose work capacity was equal to 220.45 kg/h.

Conclusions

Interesting results were obtained from the first laboratory tests carried out by the authors, whose objective was risk assessment of hand-arm vibration to the operator using portable shakers to perform olives harvesting.
The more efficient machine both in terms of operator's health and in terms of work productivity appears to be the B machine (Cifarelli). This shaker, in fact, provided, among all, the highest value of work capacity compared with a daily exposure to vibration just higher than machine A with lower labor productivity by 33%.
The results appear to be slightly different from those recorded by other authors as the tests differ in the type of machines used (Monarca et al. 2003) and in the test mode (Pascuzzi et al. 2009).

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