# Risk assessment due to transmission of vibrations from olive electrical and pneumatic harvesters to the Hand-Arm System (HAV): definition and evaluation of levels and exposure time

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## Abstract

**The paper is focused on exposure to vibration during the olive harvest for farmers of Azienda Agraria of Università Politecnica of Marche to highlight the importance of the exposure to vibrations transmitted to the hand-arm system in agriculture and its consequences on human health. To assess the exposure to mechanical vibration transmitted to operators during the olive harvest, measurements were done using a vibration measuring equipment during the regular working activity. The vibration samplings were carried out on electric and pneumatic harvesters. The measured data were compared with the prevention values for the safety requirements fixed by the normative. The analysis of the results shows that the electric harvesters transmit vibrations equivalent and in some cases higher than ones provided by the pneumatic harvesters. The paper, evaluating the risk to the hand-arm system due to vibrations, give an overview of the exposure of workers to the risks arising from vibrations to which operators are exposed when using olive harvesters.**

**Keywords:** vibrations exposure, agriculture, health and safety

## Introduction

Every day farmers are exposed to health and safety risks, due to work environment and the machineries they use. Some of these risks, like vibrations, are underestimated by workers as well since they do not represent an immediate damage for the health. Indeed, disease symptoms can appear several years afterwards. In fact the frequent use of vibrating hand-held tools can result in various chronic diseases. Technical literature presents so many studies and researches on transmission of vibrations to the hand-arm system (HAV). Nataletti *et al.* 2008 presented the Italian vibration database for risk assessment. Chetter *et al.* 1998 investigated the effects of hand arm vibrations sindrome. Dewangan and Tewari 2008 studied the characteristics of vibrations transmission in the hand–arm system and subjective response during field operation of a hand tractor.

Aldien *et al*. 2006 investigated the influence of hand forces and handle size on power absorption of the human hand–arm exposed to $z_h$-axis vibration, Bustrom 1997 investigated the influence of biodynamic factors on the mechanical impedance of the hand and arm**.** Pascuzzi *et al*. 2009 studied workers' exposures to vibrations produced by portable shakers. Monarca *et al*. 2008 studied the transmissions of vibrations from portable agricultural machinery to the Hand-Arm System (HAV), Cerruto *et al*. 2010 investigated the vibrations produced by electric shakers for olive harvesting.

The aim of this research is to give a contribution to vibrations risk assessment in particular for the hand-arm system at which operators are exposed during the working phases deriving from the utilization of electric and pneumatic harvesters. For this reason the hand-arm vibrations due to the electric and pneumatic harvesters were investigated in the Azienda Agraria of the Università Politecnica of Marche during the regular working activity. The assessment was done through direct measurements, using the adequate equipment to record the vibration metric levels of each analyzed harvesters. The electric model of the harvester utilized in the Azienda Agraria and other electric and pneumatic models were measured to give an overview of the vibrations exposure of workers to which operators are exposed during the olive harvest.

The procedure was carried out following all legal provisions and the most recent ISO standards (UNI EN ISO 5349-1:2004, UNI EN ISO 5349-2:2004). The measured data were compared with the prevention values for the safety requirements fixed by the normative (Decreto Legislativo 81 del 2008.).

**Methods and Materials**

The experimental tests were carried out in an Azienda Agraria’s olives trees field of Università Politecnica of Marche. The Azienda Agraria was created on 1993 to conduct research and development field projects on behalf of the Università Politecnica of Marche.

Landscape management and maintenance of the entire University campuses was also included in the activities. The Azienda Agraria leases 75 ha in Agugliano, ruled as integrated production, and 73 ha in Gallignano, managed as organic production, botanical garden and forest. In the Azienda Agraria only an electric model of the harvester was utilized by two operators in turn so other electric and pneumatic models were measured in same tests to give an overview of the vibrations exposure of workers to which operators are exposed during the olive harvest. To smooth the influence of external factors the harvesters were used by the same operator, expert in the use of this typology of tools due to his job activity during the olives harvesting campaigns. The tests were carried out during some days of the olive harvest in the year 2010 and in the year 2011. Table 1 shows the technical characteristics provided by manufacturers of the electric model utilized by Azienda Agraria (A1) and of other tested models.

**Table 1. Technical characteristics of the tested olive harvesters**

| Model | Engine | Description |
|---|---|---|
| A1 | Electric | It has the carbon fiber comb with a frequency of vibration of 800 strokes/minutes. The engine is placed on bottom of the bar near the handgrip. The head is inclinable in two positions and it has an harvest system at lateral oscillations. It is powered by a battery backpack. It has a weigh of 3 kg. |
| A2 | Electric | Harvesting system with double motion: while the combs oscillate, with a movement from right to left, at the same time the individual prongs move in the opposite rotary direction, creating an ellipse of 8x7 cm. The two combs move performing 1150 cycles for minute. It weighs 1,22 kg. It has a velocity of 1080-1150 rpm |
| A3 | Electric | It reaches dense areas of any tree, with a productivity up to 120 kg/hour. It is powered by 12 Volt normal battery (of a car or of a tractor). It has a special frequency rectifier that, autonomously and in an automatic manner, controls and sets the speed and the power according the efforts done by the machine. The electrical motor is inside the handle of the machine. It has a weigh of 2,2 Kg. |

| | | |
|---|---|---|
| A4 | Electric | It has a harvesting capacity 80-120 Kg/h, the weight of the harvester is 0,75 Kg, while the weight of the telescopic bar is 0,90 Kg. Its current consumption is 3-5 Ah, the supply voltage is 12 Volt, the charging time of the battery backpack is 4 hours and the charging time of the battery-holder bag is 2 hours |
| A5 | Electric | It has a frequency of vibration of 1150 strokes/minutes, the supply voltage is 12 Volt, a current consumption of 6 Ah, it has a weigh of 2,7 Kg |
| B1 | Pneumatic | It has a system "short stroke" with a frequency of vibration of 1800 strokes/minutes. The combs have the prongs with the tested profile "tuning fork". The weight of the harvester is 1,00 Kg, while the weight of the telescopic bar is 1,74 Kg. |
| B2 | Pneumatic | The combs move sideways, the one opposite to another, crossing and thus increasing the radius of action. The frequency of vibration of 1600 strokes/minutes. The weight of the harvester is 0,98 Kg, while the weight of the telescopic bar is 1,74 Kg |
| B3 | Pneumatic | It has the prongs more tapered than other pneumatic models. The frequency of vibration of 1600 strokes/minutes. The weight of the harvester is 1,00 Kg, while the weight of the telescopic bar is 1,74 Kg |

The A1 model was equipped with a carbon bar, the A3 with a plastic bar and all other models with the alluminum bars. For the tests all bars had the same length of 2 m.
The measurements were carried out respecting the indications contained in the provisions UNI EN ISO 5349-2.

The instruments used were a 4 channel vibration meter (Maestro), a vibration transducer (triaxial accelerometer) Brand PCB Piezotronics Model 356B21 and a calibrator AT01.

**Table 2. Technical characteristics of the vibration meter utilized for the tests**

| Specifications | |
|---|---|
| Precision | Class 1, ISO 8041 standard |
| Triaxial accelerometer | |
| Sensitivity | 10mV/g |
| Frequency response at 10% | 0,5 to 6000 Hz |
| Maximum value | 500g |
| Weight | 10,5g (15,9g with the hand-arm piece) |
| Monoaxial accelerometer | |
| Sensitivity | 10mV/g |
| Low cut-off frequency at 10% | 0,1 Hz |
| Maximum value | 500g |
| Weight | 18g |
| Measurements ranges | |
| 3 meas.ranges for an 10mV/g accelerometer | 0-5000m/s$^2$, 0-1000m/s$^2$, 0-100 m/s$^2$ |
| Linearity domain for peak acceleration | From 2 to 5000m/s$^2$ |
| Linearity domain for effective acceleration | From 0,2 to 600m/s$^2$ |
| Possibility to connect accelerometers of different | 100mV/g (range 0-500m/s$^2$, 0-100m/s$^2$, 0-10 m/s$^2$ |

| | |
|---|---|
| sensivities | |
| Measurement stabilisation time | 35s |
| Reference range | 0–5000m/$s^2$ |
| Hand arm vibration (calculation and display of the following values): | |
| Peak and effective accelerations on 3 axes band pass filtered (4 axis if using Aux) | 6,3-1250Hz |
| Weighted effective accelerations on 3 axes ((4 axis if using Aux) | According to wh hand arm filters of the standard ISO 8041/A1:1998 |
| Calculation and display of the following values: multiaxial equivalent acceleration on the weighted channel according to the formula: | $A_{wtot} = (a_{wx}^2 + a_{wy}^2 + a_{wz}^2)^{1/2}$ |
| Basic vibration meter | |
| Peak and effective accelerations | Band pass filtered 0,4-1000Hz or 10-1000Hz |

The measures were performed by fixing the accelerometer in two points of the bars of electric and pneumatic harvesters in ordinary working conditions, in particular in the first tests the accelerometer was fixed in the bottom of the bar near the hand of operator (control hand) and in the second tests in the middle of the bar near the other hand of the operator (auxiliary hand). The utilized accelerometer was firmly fixed on the handle of the harvester, close to the hand of the operator, but not affecting the normal course of action. To fix the accelerometers on the harvester, specific adaptor with a plastic band was utilized; while the accelerometer cables, in order to avoid distortions in the measured signal or eventual damages, was fixed near the transducer with adhesive tape. These measurements were carried out for every harvester model during the regular working activity.

Particular attention was used during the fixing process of the accelerometers on the auxiliary and command handles, in order to have each axis oriented in the directions imposed by the provisions UNI EN ISO 5349-1 (basicentric coordinate system).

The equivalent accelerations weighed up in frequency on the single axis ($aw_x$,$aw_y$,$aw_z$) and total ($A_{wtot}$,), acquired simultaneously, were measured during working load that is the real dynamic behavior of the harvesters. The measurement time was 300 s. The tests for every harvester models were repeated three times. To make the measurements repeatable, it was necessary to equalize the maintenance conditions of the instruments under test. Before each test series and at the end of the series a calibration of the measurements instruments was carried out. Comparisons among different harvesters were carried out in standard conditions, keeping constant all external factors (operator's influence, operating modes, load parameters).

To assess the vibrations exposure level transmitted to the hand-arm system the value of daily exposure standardised to an eight hour reference period A(8) (m/$s^2$) for each olive harvesters was determined, estimated on the base of the root of the sum of the squares ($A_{wtot}$) of the root mean square value of the frequency-weighted accelerations, calculated on the three orthogonal axes x, y, z, in agreement with the ISO 5349 – 1. The A(8) values were calculated through the following formula:

$$A(8) = A_{wtot} (T/8)^{1/2} \quad (1)$$

$$A_{wtot} = (a_{wx}^2 + a_{wy}^2 + a_{wz}^2)^{1/2} \quad (2)$$

where:

T is the total daily vibration exposure (hours);
$a_{wx}$ $aw_y$ $aw_z$ are the values of frequency-weighted acceleration (m/s$^2$) on the *x*, *y*, *z* axes.

However, since it was noticed that in the Azienda Agraria only two operators worked using the olive harvester in total for three hours for day during the olive harvest in their regular working day, it was considered a total vibrations exposure time of three hours (T = 3 hours) for each worker. Thus, in order to test a more realistic level of exposure for the operators, the respective A(8) values referred to 3 hours of exposure were calculated.

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 compare to analyse the differences related to different olive harvesters under test and they were compared with the prevention values for the safety requirements fixed by the normative to make the employers able to organize adequate work schemes, respecting the health of the workers.

**Results**

The vibration samplings were carried out on electric and pneumatic harvesters.

The values $a_{wx}$, $a_{wy}$ and $a_{wz}$ were measured, according to the previsions contained in UNI EN ISO 53491, during the three repetitions made for each harvesters at working load; the total equivalent accelerations were calculated. Table 2 show the accelerations related to the hand-arm. For each column are respectively indicated the A(8) values referred to a three hours exposure period and $A_{wtot}$ values. For the harvesters under test the values related to each limb are indicated. In any case, the calculation of the daily exposure level was done considering the higher value.

**Table 3. $A_{weq}$ and A(8) values for each harvester under test**

| Model | Operative conditions | $A_{weq}$ (m/s$^2$) Control hand | $A_{weq}$ (m/s$^2$) Auxiliary hand | A(8) (m/s$^2$) |
|---|---|---|---|---|
| A1 | working load | 21,0 | 12,5 | 12 ,86 |
| A2 | working load | 14,7 | 9,1 | 9,00 |
| A3 | working load | 27,3 | 19 | 16,71 |
| A4 | working load | 8,5 | 14 | 8,57 |
| A5 | working load | 5,8 | 8,2 | 5,02 |
| B1 | working load | 7,2 | 11 | 6,74 |
| B2 | working load | 11,8 | 16,6 | 10,17 |
| B3 | working load | 10,7 | 11,6 | 7,10 |

The analysis of the results shows that the electric harvesters transmit vibrations analogous and in some cases higher than ones provided by the pneumatic harvesters. The pneumatic and electric harvesters having the engine at the top of the bar show higher vibrations levels near the auxiliary hand, instead the electric harvesters having the engine located at the bottom of the bar show higher vibrations levels near the control hand. However, the vibrations given off by the harvesters correspond to A(8) values greater than the daily exposure limit value established by the European directive 2002/44/CE. All times are clearly incompatible with the length of a standard work-day in agriculture. Thus, being a high risk situation the employer must take immediate measures to lower the exposure, individuating the causes of the overcoming and taking the protection and prevention measures to avoid a new overcoming.

**Conclusion**

The present research, evaluating the risk to the hand-arm system due to vibrations, give an overview of the exposure of workers to the risks arising from vibrations to which operators are exposed when using olive harvesters. The results of the carried outs tests, point out the high values of acceleration transmitted to the hand-arm system produced by the electric and pneumatic harvesters. The Italian laws, with the object to evaluate of human exposure to hand-transmitted vibration, prohibit the overcoming the short period exposure limit value of 20 $m/s^2$ and impose a daily eight hours exposure limit value of 5 $m/s^2$. For all examined harvesters, the values are greatly higher than the limit ones laid down in the law in force.

The research on agro-forestry machineries may encourage operators and constructors to adopt ergonomic instruments to guarantee high work performances, as well as workers health and safety. In design phase, in fact, the in-depth study of some technical aspects is very important to have an effective reduction of the effects of the exposure to damaging vibrations.

These considerations are susceptible to be integrated by further investigations.

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