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Abstract

To provide more effective evaluations of hand arm vibration syndromes caused by hand held olive beaters, this study focused on two aspects: the acceleration measured at the tool pole and the analysis of the impulsivity, using the crest factor. The signals were frequency weighted using the weighting curve W_h as described in the ISO 5349-1 standard. The same source signals were also filtered by the W_{h-bl} filter (ISO/TS 15694), because the weighting filter W_h (unlike the W_{h-bl} filter) could underestimate the effect of high frequency vibration on vibration-induced finger disorders. Ten (experienced) male operators used three beater models (battery powered) in the real olive harvesting condition. High vibration total values were obtained with values never lower than 20 ms^{-2}. Concerning the crest factor, the values ranged from 5 to more than 22. This work demonstrated that the hand held olive beaters produced high impulsive loads comparable to the industry hand held tools.

Key words: HAV, impulsivity, olive harvester

1. Introduction

The problem of the high vibration levels to the hand-arm system using vibrating tools and machines has been well known for many years. Epidemiologic aspects of the relationship between vibration exposure and human response have been investigated (Gemne, 1997; Bovenzi, 1998; Lundborg et al., 1998; Bovenzi, 2005).

The prolonged use of hand held vibrating equipment can lead to the hand arm vibration syndrome (HAVS) that refers to a combination of neurological, muscular, circulatory, bone and joint disorders (Griffin et al., 2003). Power or pneumatic drills in industry, chainsaws, beaters, brush cutters in agro-forestry may be the cause of HAVS. It is not completely well known how vibration causes the condition of the HAVS. Neurological and circulatory diseases are, for example, probably due to slight but repeated injuries to the small nerves and blood vessels in the fingers (Stoyneva et al., 2003).

The main parameters interested in the HAVS evaluation (as requested by the European Directive 2002/44/EC) are the vibration magnitudes (expressed as vibration total values) and the daily exposure time. The vibration total values are calculated using the ISO 5349-1: 2001 standard, to frequency weight the signals through the weighting curve W_h.

Many investigations have been addressed to study the magnitude of the vibration total values and the duration of the exposure (or both of them) in different work environments (Pyykkö et al., 1976; Palmer et al., 2000; Gerhardsson et al., 2005; McDowell et al., 2008; McCallig et al., 2010). Acceleration peaks generated by tools may also be further parameter influencing the harmfulness exposure to vibration.

It can be critical the presence of high peaks in the acceleration signal (i. e. the impulse character of vibration in some occupations), because high-frequency components may be hazardous in the aetiology of vibration syndrome. The vibration impulsivity could create shock waves in tissues and these waves may be transmitted at higher velocity and to larger body areas than non impulsive vibration (Pyykkö 1986, Starck, 1984).

In the case of the whole body vibration evaluation, the ISO 2631-1: 1997 standard states that the r.m.s. (root mean square) method is the basis for measurements for crest factors (CF) less than 9. In cases where the basic evaluation method may underestimate the effects of vibration (high crest factors, occasional shocks, transient vibration), alternative measures should also be determined. The standard proposes two alternative measures: the running r.m.s. or the fourth power vibration dose value.

The crest factor is not considered in the hand arm vibration exposure, also if some studies were addressed to understand if it was appropriate to evaluate the severity of the hand transmitted vibration as peaks or r.m.s. accelerations (Louda et al., 1994; Ye et al., 2012).

Some investigations on the peaks presence in acceleration signals were conducted. These works were mainly addressed to the industrial sector (Engstrom and Dandanell, 1986; Starck and Pyykkö, 1986; Riedel and Münch, 1998; Burström and Sörensson, 1999; McDowell et al., 2008), while few researches on the agro-forestry area (Schäfer et al., 1984; Nakamura et al., 1998) were carried out. This is mostly due to the misperception that the farmers and the agro-forestry operators use few vibrating equipment and, whereas they use them, the exposure time is negligible. In the last years, instead, new tools generating high acceleration levels and impulsiveness, comparable to the construction and mining sectors, have been manufactured: among these equipment there are the hand held olive shakers driven by a little two stroke (or pneumatic or electric) engine.

The hand held olive harvesters have a low weight (from 2 to 15 kg, the electrics are the lightest). The main causes of the elevated vibration levels caused by these machines are their lightness, the high tangential velocity of their sticks tips and the pole features (material, diameter and length, Manetto et al, 2012).

The beater mass must be low because the operator inserts the beater sticks into the foliage about 30-40 times/minute for more than 4 hours/day.

The high tangential velocity of sticks tips is also necessary to detach the olives. These fruits have a negligible mass (e.g. the fruits of the *Leccino* cultivar have an average mass of 1.4 g) but a great force is necessary to detached them from the branches (the average fruit removal force for the Leccino is 2.8 N), as Lavee et al. (1982) studied.

The result of the two components (tool lightness and high detachment force) is the high acceleration level, which fixes around 15-25 ms^{-2} (Monarca et al., 2007; Pascuzzi et al., 2009; Cerruto et al., 2009; Aiello et al., 2010; Çakmak et al., 2011; Deboli et al., 2014).

It is therefore interesting to analyze the vibrational behaviour of these machines not only considering the vibration total level, but also the frequency analysis of the signals, as requested by the Annex F (Informative) of the ISO 5349-1.

This standard requires to report (unweighted) one-third-octave band r.m.s. acceleration amplitudes on the frequency range of the measurement system, in addition to frequency weighted magnitudes. Unfortunately nobody applies this standard request.

Aim of this work was to analyze the acceleration signals in field operations using three different types of electric hand held olive shakers used by ten male operators.

These hand held harvesters have an electric engine and are called beaters: they have a head with oscillating carbon fiber sticks and the harvesting is obtained by direct impact of sticks on olives or by vibration transmitted to the willowy branches.

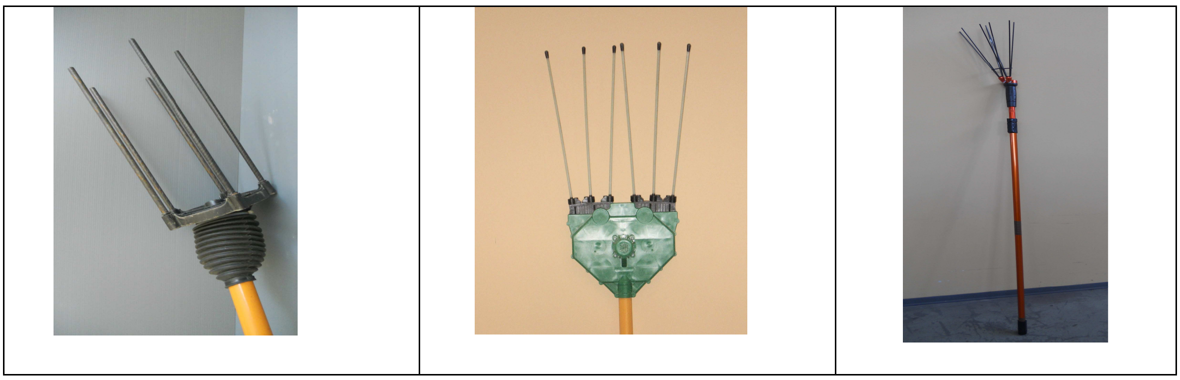
The values analysis was carried out weighting the signals with both the standardized frequency weighting filter W_h (ISO 5349-1) and the band limiting weighting filter W_{h-bh}. The latter is a weighting filter with a flat frequency range between the cut-off frequency of 6.3 Hz and 1250 Hz. The W_{h-bl} filter is a band limiting component of W_h, to verify the real frequency distribution of the vibration energy content. Dong et al. (2004), Bovenzi (2012), Brammer and Pitts (2012) and Pitts et al. (2012) found that the standardized frequency weighting filter W_h could underestimate the effect of high frequency vibration on vibration-induced finger disorders. It could be therefore interesting to analyze vibration signals in a wider range of frequency, without filtering action.

The high velocity of the beater sticks during the work and the machine lightness were moreover foreboding of impulsive loads caused by the sticks impacts against the willowy branches.

2. Materials and methods

2.1 The electric beaters

The tested beaters were of three different manufacturers (technical characteristics are reported in Table 1): they were all electric machines, beater type, battery powered (12 V) with an head equipped with oscillating sticks (Fig. 1). Only the #3 featured an electronic control to decrease the number of beats per minute when it was in the idling state. The olive beaters do not have handles. The terms ‘front’ and ‘rear’ used in this article, refer to the operator’s hands position on the beater pole (Fig. 3(b)).



Beater #1 Beater #2 Beater #3

Fig. 1. The tested beaters.

Table 1. Technical characteristics of the tested beaters.

Technical data	#1	#2	#3
Beats per minute (bpm)	1086	1300	400-1400
Mass without power cord (g)	2200	2200	1650
Telescopic pole length (mm)	2500-4500	2200-3400	1700-3100
Sticks number	6	6	8
Sticks length (mm)	360	360	350
Stick diameter (mm)	10	6	5
Stick mass (g)	19.3	25.6	11.2
Stick material	Carbon fiber	Special composite	Carbon fiber
Supply voltage (V)	12 - 24	12	12
Current consumption (work) (A)	5 - 4	4	2 - 5
Current consumption (stand by) (A)	-	-	0.5
Engine position	rear	front	front

The electric beaters were initially used in laboratory in the idling state to acquire some functional parameters (acceleration and velocity) along a single stick, as peak values.

A mono-axial accelerometer (Brüel & Kjær 4374, miniature piezoelectric charge accelerometer 0.65 g of mass), fixed with cyanoacrylate adhesive, was placed 1 cm from the tip of a stick (Fig. 2), with the *X* axis along the vertical line and three acquisitions of 20’ each were performed. Combining the peak acceleration with the fundamental frequency of the stick motion, the tip stick speed was then obtained.

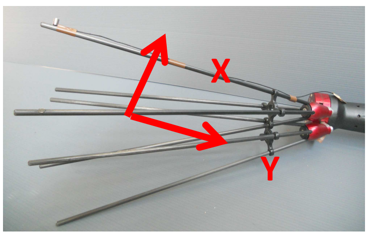


Fig. 2. Position of the mono axial accelerometer over the beater stick and *X*-*Y* axes direction.

2.2 Field sites and cultivars

The field tests were carried out during an olive harvesting campaign in Northern Italy, in a site located at Verzuolo (Cuneo, Italy), property of the Environment and Agriculture Institute ‘P. Barbero’, with Leccino olive variety. The coordinates of the orchard are 44° 35' 45,60'' N and 7° 29' 4,56'' E.

2.3 Operators

Ten healthy men, who were regularly exposed to vibration, were involved in the olive harvesting. The mean age of the subjects was 40.8 years (range 27-63 years), the weight 81 kg (range 65-95 kg) and the height 177 cm (range 170-184 cm).

2.4 HAV measurements

2.4.1 Measurement chain

According to the EN ISO 20643: 2008 standard, two tri-axial accelerometers ICP (Integrate Current Preamplifier) by PCB (SEN020 model, 1 mV/g sensitivity, 10 g mass) were fastened on the harvester pole (EN ISO 20643/A1: 2012) by metallic screw clamps.

The signals from accelerometers were stored on the laptop using a National Instruments data acquisition card (NI 9234). Later the data were processed using the LabView software (National Instruments, 2012).

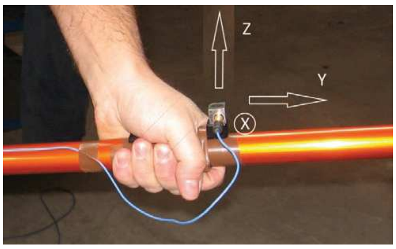
The rear accelerometer was fixed near the power switch positioned at the end of the pole, where there is the hand of the right-handed operator. The front accelerometer was positioned according to operator’s anthropometric characteristics (Fig. 3(b)).

Axes directions are reported in figure 3(a). The measurement chain was previously calibrated.

DC-shift presence (as suggested by Maeda and Dong, 2004 and Paddan, 2004) was verified. The 1/3 octave analysis did not reveal any low frequency energy.

Three series of five consecutive tests were carried out for each examined beaters and for each operator, both at front and at the rear hand position in the idling state and during the field work.

In the idling state all measurements were carried out with the beaters switched on and hold by the operator without working.



(a) (b)

Fig. 3. Accelerometer positions and vibration measurement directions (a). Front and rear hand position on beater pole (b)

2.4.2 W_h weighted (a_{hv} ISO 5349-1) and $W_{h\text{-}bl}$ flat weighted (a_{hF} ISO/TS 15694) vibration total values

The vibration total values analysis was performed both at idling and work conditions because, as the CEN 15350 states, the fruit harvesters are used for 1/7 of their time in an idling condition (ignition, displacement, rest) and for 6/7 at the full load (work condition).

The acceleration were acquired for each beater and for each hand position (front and rear, of the ten operators and then separately analyzed The acquisition time for each test was at least two minutes, to obtain a stabilized signal.

The vibration data were processed in order to obtain the one-third octave bands and these signals were therefore weighted using the weighting curve W_h as described in the ISO 5349-1 standard. The vibration total value (a_{hv}) was calculated as the square root of the sum of the squares (r.m.s.) a_{hwx}, a_{hwy} and a_{hwz} along the individual axes (Eq. 1):

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (1)$$

The previous one-third octave bands were also weighted by the $W_{h\text{-}bl}$ filter (as explained in the ISO/TS 15694 standard) to obtain the flat weighted a_{hx}, a_{hy} and a_{hz} accelerations (Fig. 3(a) for the reference coordinate system).

The vibration total value (a_{hf}) for each tri-axial accelerometer was then calculated using the following formula (McDowell et al., 2008; Bovenzi, 2012) (Eq. 2):

$$a_{hf} = \sqrt{a_{hx}^2 + a_{hy}^2 + a_{hz}^2} \qquad (2)$$

2.5 Crest factor analysis

Considering the high acceleration values of these machines and their lightness, the crest factor CF_h (h is for hand), was calculated for the field tests.

The crest factor is defined as the ratio of peak values to the average r.m.s value and indicates how extreme the peaks are in a waveform. High crest factors are a sign of the presence of peaks and impulses.

The ISO 5349-1 does not refer to the crest factor, also if it declares that the impulsiveness is one of the factors influencing the probability of white-finger symptoms. The ISO/TS 15694, instead, gives information for the calculation of the crest factor using the accelerations filtered by the $W_{h\text{-}bl}$ curve.

Moreover crest factor of unweighted accelerations were studied by some Authors (Schäfer et al., 1984; Nakamura et al., 1998; Riedel and Münch, 1998). For these reasons the crest factor of the flat weighted acceleration, CF_h, was calculated.

The crest factor of the flat weighted acceleration, CF_h is obtained by dividing the peak value of flat weighted acceleration ($a_{hF,\,PV}$) by the r.m.s. value of the flat weighted acceleration measured in the same time period T ($a_{hF,\,RMS,\,T}$) (Eq. 3):

$$CF_h = \frac{a_{hF,PV}}{a_{hF,RMS,T}} \qquad (3)$$

This quantity combines the peak value of the signal with the energy equivalent r.m.s. value and therefore describes the impulsiveness of the flat weighted signal.

The r.m.s. values and the peaks were calculated along each axes, each hand position and for all the beaters and the operators. Afterward, the CF_h was obtained.

2.6 Data analysis

All the acquired data were organized into spreadsheets and then processed using the IBM SPSS Statistics 21 software package. Front and rear hand position data were separately analyzed.

3. Results and discussion

3.1 Comparison among beaters

The analyzed beaters produced different acceleration values, related to their specific sticks movements. The sticks of the beater #2 move in an unique plane, sweeping a 35° angle, while the sticks motions of beaters #1 and #3 describe cones which vertexes are positioned in the beater head.

The fundamental frequency was around 20 Hz, while the peak acceleration measured on the tip of the sticks was higher for the beater # 2 (1200 ms^{-2}, Table 2).

Table 2. Beater tip sticks acceleration and speed.

Beater	Foundamental frequency (Hz)	Tip stick acceleration (ms^{-2})	Tip stick speed (ms^{-1})
#1	18.1	608	5.3
#2	21.2	1200	9.0
#3	22.5	858	6.1

3.2 The vibration total value (a_{hv}) analysis (ISO 5349-1)

The difference among the vibration levels were more evident in the idling state. During the work the acceleration values were levelled by the sticks strikes against the tree branches.

3.2.1 Idling state

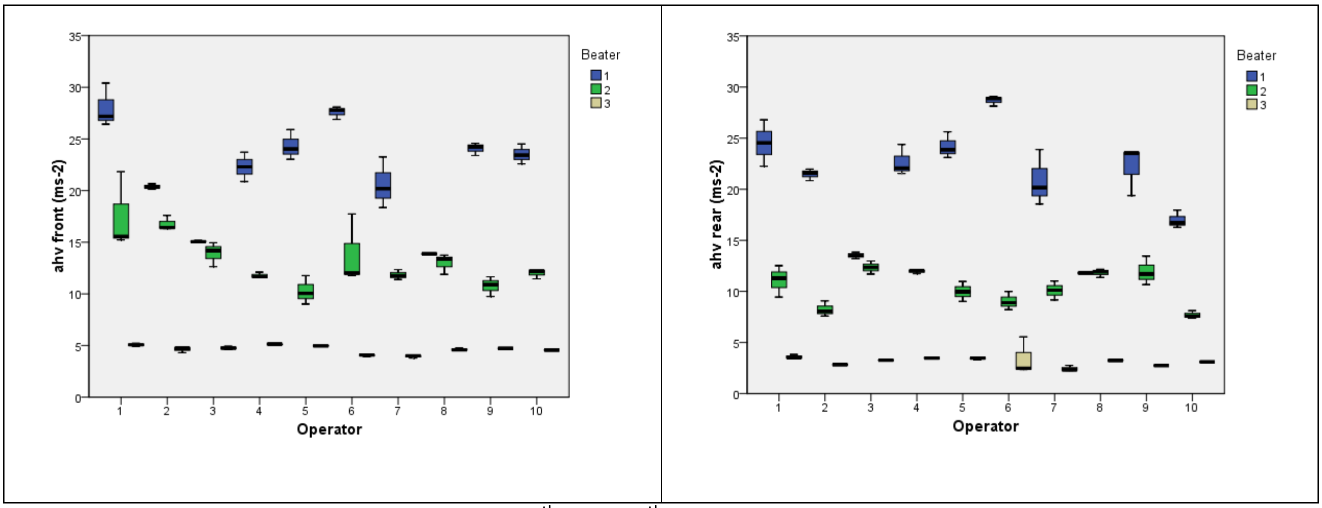


Fig. 4. Boxplots of median and quartiles (25th and 75th at the box borders) of the vibration total values (a_{hv}) of the three examined beaters and of the ten operators at the front (left) and rear (right) hand positions at the idling state tests.

In all the investigated beaters it was observed that the working gears and the heads were not dynamically balanced: during the idling state their inertial motion and the machine lightness therefore produced high vibration levels over the machine pole and consequently on the hand arm system.

In the idling state, however, the vibration total values were not the same for the three beaters and the differences are evident in the two box plot graphs (Fig. 4), both at the front and at the rear hand position. The acceleration values were around 4 ms^{-2} for the beater #3 (with a maximum at about 6 ms^{-2} for the operator 6 at the rear hand position) and increased to 10-13 ms^{-2} in the beater #2 (with higher values at the front hand position, especially for operators 1 and 6) till to 22 ms^{-2} in the beater #1 (with an higher data variability inside each operator and with an acceleration stability at the rear hand position). As long as the beaters were the main responsible of the acceleration differences (at both the hand positions), the operator influence was evident for the beaters #1 and #2 (Fig. 4).

3.2.2 Full load condition

Despite of the distinct beaters action in the idling condition, visible in figure 4, figure 5 depicts a different scenario in full load condition, with high vibration total values mixed among the three beaters, especially at the front hand position.

In this case the values were in average higher than 20 ms^{-2}, with maximum that reached 34 ms^{-2} for the beater #2 and many registered data around 30 ms^{-2}. Concerning the rear hand position, only the beater #2 produced data lower than 20 ms^{-2}, while for the beaters #1 and #3 the averages were always around this value.

During the work, the beater #3 gave the highest averaged vibration total values, especially in the front hand position (Table 3), with a significant difference among the beaters, as stated by the Kruskal Wallis non parametric test procedure, whereas the same test underlined a likeness among the operators at the rear hand position (sig. = 0.42).

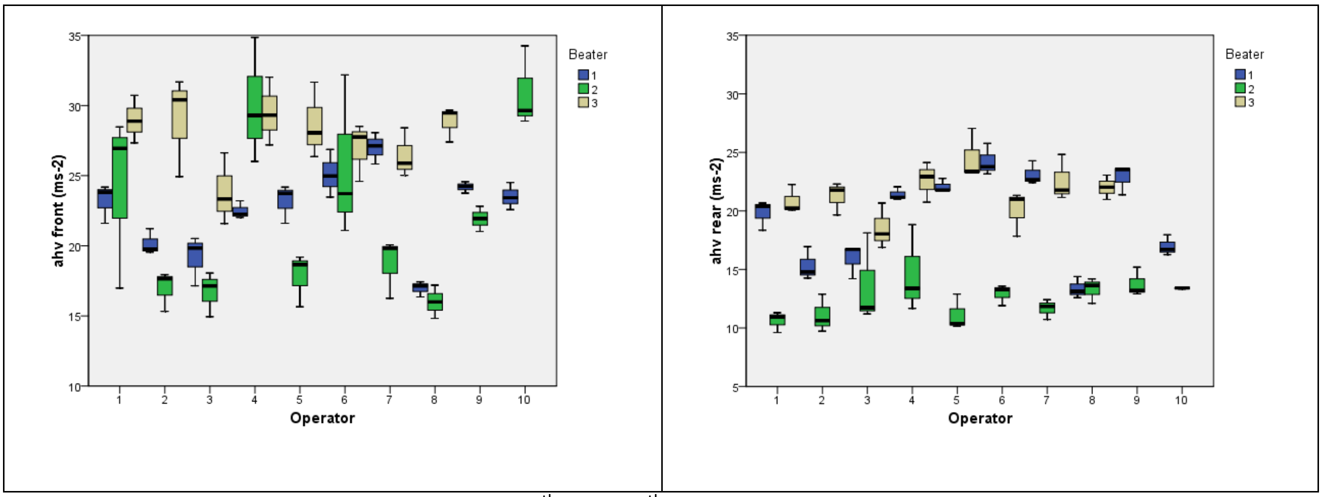


Fig. 5. Boxplots of median and quartiles (25th and 75th at the box borders) of the vibration total values (a_{hv}) of the three examined beaters and of the ten operators at the front (left) and rear (right) hand positions at the full load condition tests.

Table 3. Analysis of the vibration total values a_{hv} at the full load conditions (at front and rear hand position) and Dunnett's multiple comparison procedure among the means (different letters in the columns denote a statistically significant difference at the 95% confidence level) of the three beaters.

	a_{hv} front (ms^{-2})				a_{hv} rear (ms^{-2})			
Beater	Average	SD	Min	Max	Average	SD	Min	Max
#1	22.5 a	3.0	16.3	28.1	19.5 d	3.8	12.6	25.8
#2	21.9 b	6.1	14.8	34.9	12.6 e	2.1	9.6	18.8
#3	27.8 c	2.7	21.6	32.0	21.6 f	2.3	16.9	27.0

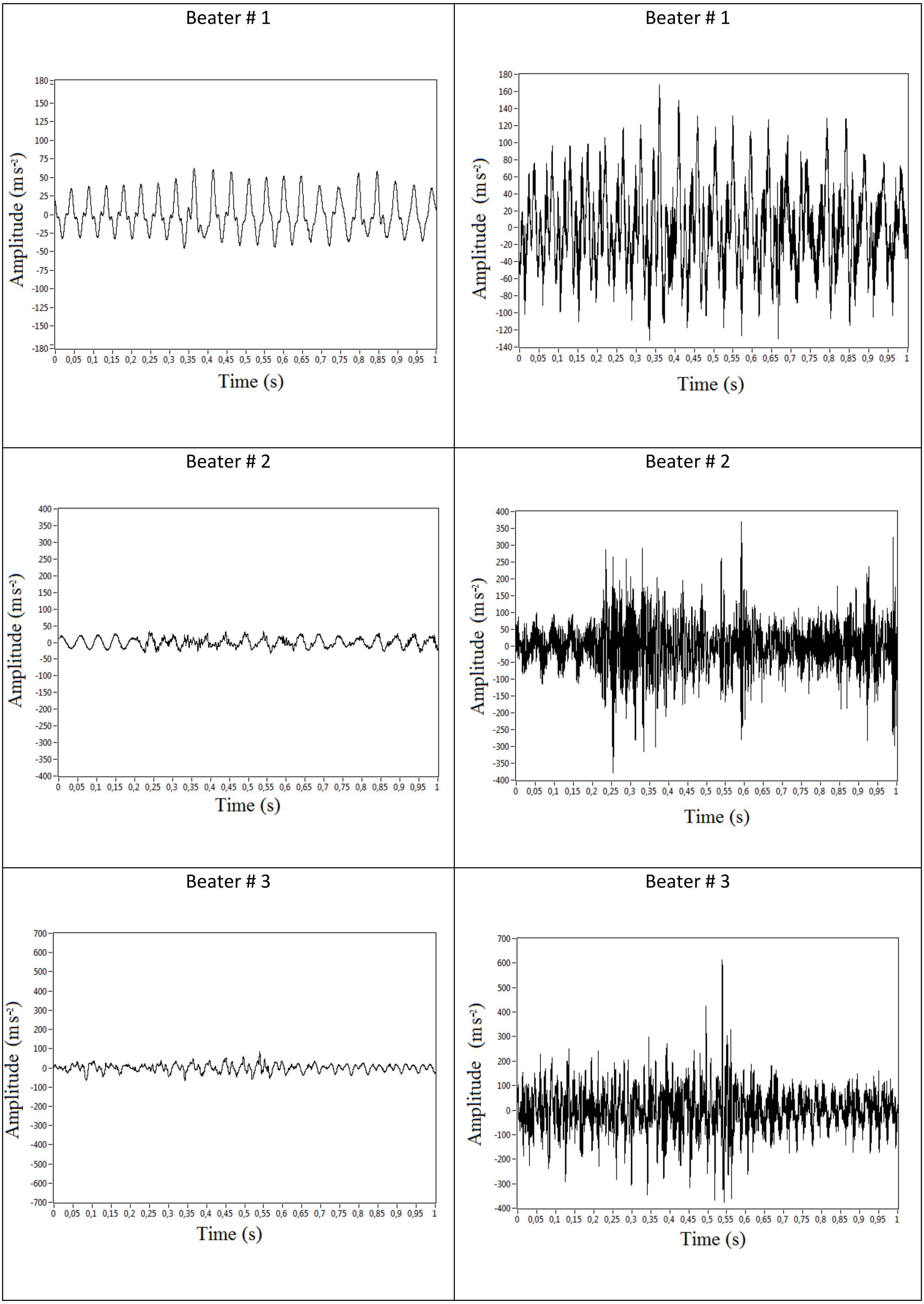
3.3 The peaks analysis

Considering the highest vibration total values at the front hand position, during the peak analysis only the acquisitions at this point were used. The data discussed up to now were obtained applying the ISO 5349-1 standard weighting curve W_h. Because of the high acceleration values obtained, vibration levels were compared using the $W_{h\text{-}bl}$ filter, to highlight the presence of possible peaks.

In figure 6 there are the time histories of six recorded sequences, related to the three beaters used by the operator #4. The graphs show how the time histories in the identical intervals are different if the same signal is weighted by W_h (ISO 5349-1, left), or by the $W_{h\text{-}bl}$ filter (right). For example, the beater #2 shows peaks higher than 300 ms^{-2} in the flat weighted graph, while in the same W_h weighted sequence they lower to a maximum of 42 ms^{-2}.

The peaks represent the beater impact against the tree branches and show their impulsiveness responses: similar results were obtained for the other 2 couples of graphs of the beaters #1 and #3.

Because high peaks were present in acceleration signals filtered by $W_{h\text{-}bl}$, the next step was then to analyse their frequency distribution.



Beater # 1
Amplitude (ms⁻²)
Time (s)
Beater # 1
Amplitude (ms⁻²)
Time (s)
Beater # 2
Amplitude (ms⁻²)
Time (s)
Beater # 2
Amplitude (ms⁻²)
Time (s)
Beater # 3
Amplitude (ms⁻²)
Time (s)
Beater # 3
Amplitude (ms⁻²)
Time (s)

Fig. 6. Time histories of six recorded sequences, related to front hand position of the three beaters used by the operator #4 (W_h weighted signals: left; W_{h-bl} weighted signals: right).

The one-third octave bands frequency analysis was then considered to appreciate the frequencies energy distribution.

In figures 7, 8 and 9 the W_h (dot blue) and the W_{h-bl} (continuous red) averaged weighted signals at the different frequencies for the three beaters and all the ten operators during the field work are showed. It is evident that the higher energies are located after 16 Hz, where the ISO 5349-1 weighted curve starts to progressively cut the acquired values (Fig. 11), but it is after 63 Hz that the value flattening is greater, as is visible in figures 7, 8 and 9.

The graph of figure 7 shows the vibration energy of the beater #1 centred in the two one-third octave bands corresponding to 20 and 63 Hz, where the 20 ms^{-2} values are exceeded. Another energy peak is around 1000 Hz, while the energy content is lower between 100 and 500 Hz.

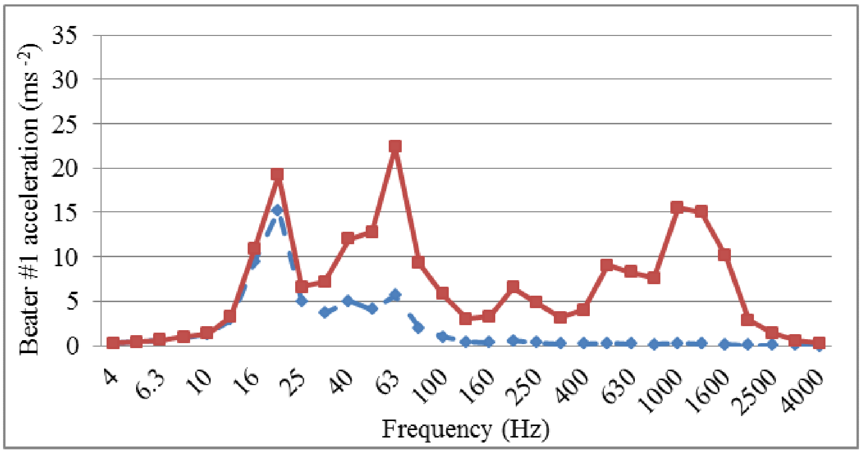


Fig. 7. Signal frequency analysis of the beater #1 (W_h weighted: dot blue line, W_{h-bl} flat weighted: continuous red line).

The construction characteristics of the beater #2 led to concentrate the vibration energy in some well defined one-third octave bands: 20 (the fundamental), 400, 500 and 630 Hz. Also in this case the hand arm system of the operators was solicited by acceleration values around 20 ms^{-2} r.m.s (Fig. 8).

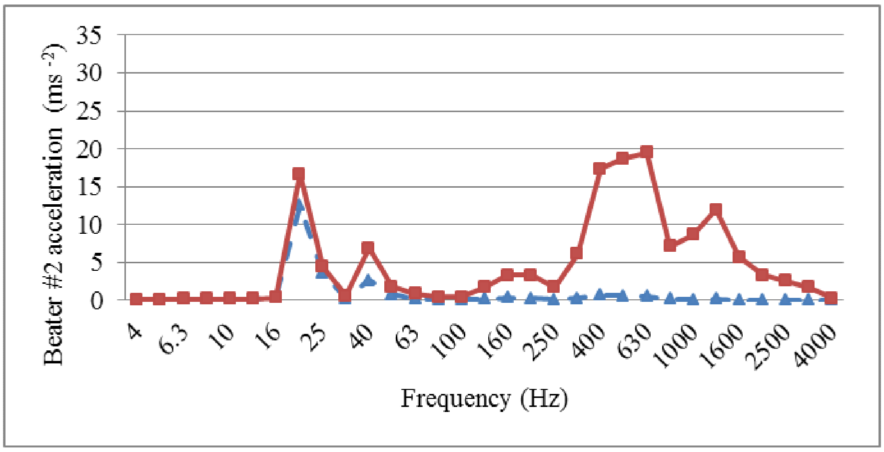


Figure 8. Signal frequency analysis of the beater #2 (W_h weighted: dot blue line, W_{h-bl} flat weighted: continuous red line).

The vibration energy distribution of beater #3 was quite uniform: compared to the other beaters, it vibrated more, showing an acceleration value higher than 30 ms^{-2} at 63 Hz (Fig. 9). From this frequency on, the flat weighted acceleration was always higher than 12 ms^{-2}.

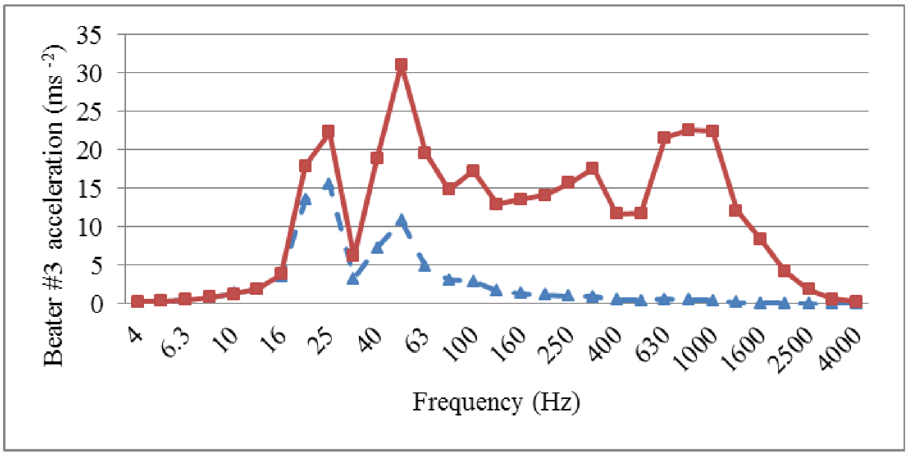


Fig. 9. Signal frequency analysis of the beater #3 (W_h weighted: dot blue line, $W_{h\text{-}bl}$ flat weighted: continuous red line).

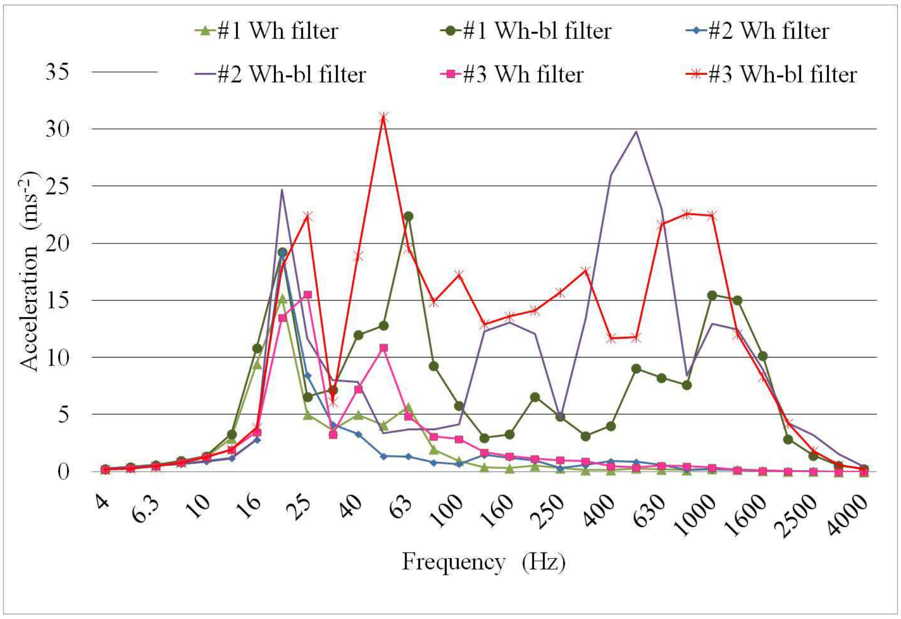


Fig. 10. Signal frequency comparison of beaters #1, #2 and #3

The overlap of the three beater acceleration values shows their fundamental frequency at 18-22 Hz (as discussed in chapter 3.1). There are two sets with high vibration energy in the flat weighted curves: the first between 40 and 200 Hz and the latter between 400 and 1250 Hz.

The $W_{h\text{-}bl}$ filtered signals show different vibration energy distributions produced by the different operating modes of the three beaters. The peaks of beater # 1 acceleration spectrum occur at about 63 and 1000 Hz, around at 160 and 500 Hz in the beater #2, while the peaks of beater # 3 are about at 50 and 1000Hz. Energy peaks are heavily reduced by the ISO 5349 filter, as observed also by Brammer and Pitts (2012) for other machines.

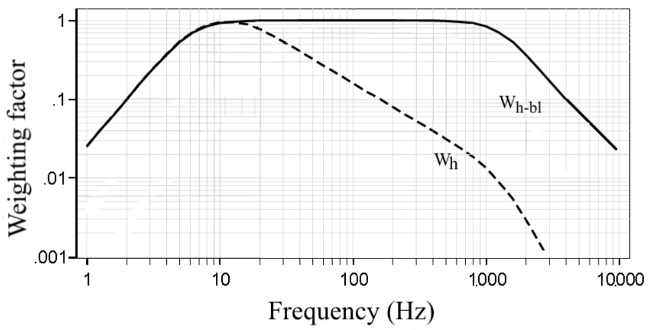


Fig. 11. Comparison of frequency weighting curves. W_h is the frequency weighting as described in ISO 5349-1: 2001; W_{h-bl} is the band-limiting component of W_h (6.3 – 1250 Hz).

3.4 The crest factor analysis

Given the feature of these machines, especially their lightweight and the high acceleration levels, the crest factor analysis for all the take-overs was also considered. In Table 4 the descriptive analysis of the calculated CF_h is showed as well as the results of the post hoc Dunnett test about the likeness among the axis values. There are similarities between the beater #1 and #3 *X* axis and between the beater #1 and #2 *Z* axis: also if the variability inside each CF_h group is high (see the SD details), it is however interesting to appreciate how high are all the values, especially along the Y axis of the beater #2. The high variability it is always due to the machine characteristics, as well as to the sticks impacts against the branches and to the different operators' behaviour.

Table 4. Descriptive analysis of the crest factors CF_h along the three axes of the three beaters at the at the front and rear hand positions and Dunnett's multiple comparison procedure among the means (different letters in the columns denote a statistically significant difference at the 95% confidence level).

	CF_h Front				CF_h Rear			
	Min	Max	Average	SD	Min	Max	Average	SD
X #1	4.9	11.9	7.2 (a*)	1.6	5.3	12.7	7.7 (h)	1.8
X #2	9.4	20.6	14.0 (b)	2.5	8.4	16.7	12.0 (i)	2.0
X #3	6.2	8.9	7.5 (a*)	0.7	7.0	11.8	9.0 (l)	1.2
Y #1	8.2	20.2	12.7 (c)	3.1	7.3	20.3	11.3 (m)	2.8
Y #2	10.9	22.8	14.3 (d)	2.4	10.7	21.5	16.3 (n)	3.2
Y #3	7.3	12.8	9.6 (e)	1.5	7.3	14.2	9.2 (o)	1.6
Z #1	5.4	14.2	9.1 (f**)	2.1	6.9	21.1	11.0 (p***)	3.8
Z #2	6.4	15.2	9.7 (f**)	2.0	6.2	19.7	12.0 (p***)	3.8
Z #3	6.9	22.4	13.6 (g)	4.4	10.6	16.9	13.9 (q)	1.8

*: sig=0.59, **: sig=0.43, ***: sig=0.27

The beater #2 shows higher values (especially along the *X* and *Y* axis), but it may be observed that the CF_h values are alike high for all the three beaters.

4. Discussion

According to the European Directive 2002/44/EC, the beaters studied in this work could not be used more than 15-25 minutes/day to stay under the time limit value (4-6 minutes for the time action value), because their vibration total values were never lower than 20 ms^{-2}, as also obtained by other Authors which used similar beaters (Manetto et al., 2012, Calvo et al., 2014). Also if these machines produce high acceleration values, they are widely spread in the olive sector, because they triple the daily harvest productivity. During the field tests it was observed that some operators directed the beater head among the branches and, when the sticks were into the foliage, they then loosened the hand grip force: this fact could justify some high vibration levels measured and the presence of high acceleration peaks. Also other studies (Pascuzzi et al., 2009; Vergara et al., 2008; Costa et al., 2013) revealed the hand arm vibration correlation to the operator behaviour during the olive harvesting, because the less experienced operators tended to tighten the beater pole, whereas the most skilled had an attitude to release the grip.

Concerning the crest factor, the values obtained in this work ranged from 5 to more than 22. These data were often higher than Schäfer et al. (1984), that obtained average CF_h of 1.8, 2.2, 2.9, 5.5, 7.9 and 10.2 respectively for: electric grinder, chain saw, electric hammer-drill, pneumatic hammer, pneumatic riveting hammer, pneumatic nailer. Similarly, Nakamura et al. (1998) studied the vibration produced by a chain saw and a pneumatic nailer in terms of impulsiveness regard hand exposure. They found CF_h values of 2.2 for the chain saw and 9.5 for the pneumatic nailer (always for the flat weighted acceleration) and their tests demonstrated that impulsive vibration with a crest factor of 9.5 affects finger circulation 4 minutes after the exposure starts. Nelson (2004) suggested that if the crest factor of the vibration is important, there is no reason to suppose that frequency weighted r.m.s. is the most appropriate averaging method.

Other authors have studied the problem of the impulsiveness load over the hand arm system (Burström and Sorensson, 1999, Dong et al. 2008) and they agreed that the evaluation of the impulsiveness using the frequency weighted r.m.s. acceleration level (ISO 5349-1) must be reconsidered.

In this work high differences were found between the W_h weighted and the flat weighted acceleration values in all the examined beaters (figures 7, 8 and 9) and consequently the ratio between the averaged vibration total values ($\bar{a}_{hf}/\bar{a}_{hv}$) was never less than 2.32 (Table 5).

Table 5: Ratio between the averaged flat weighted and W_h weighted vibration total values ($\bar{a}_{hf}/\bar{a}_{hv}$) of the three examined beaters.

$\bar{a}_{hf}/\bar{a}_{hv}$	Front (ms^{-2})	Rear (ms^{-2})
Beater #1	2.32	2.16
Beater #2	2.92	3.23
Beater #3	3.04	4.15

If the vibration total values differ of a factor of two, three, or more (due to different frequency weighting systems), the resulting exposure action values and exposure limit values could lead to different degrees of risk using the same tool.

Also Griffin (2004), in his studies, found that the difference between the W_h weighted and the flat weighted curves was very high.

In the case of vibration induced white finger (VWF), other studies (Bovenzi, 2012; Griffin, 2012; Pitts et al, 2012) established that frequency weighting W_h used in ISO 5349-1 provides a less accurate prediction than obtained with no frequency weighting, especially at medium and high frequencies.

Also Donati (2001) some years before suggested that the standardized weighting curve was not adapted for the assessing of the VWF hazards and proposed to not weight the vibration emitted by tools.

Tominaga (2005) studied a new weighting curve, which could better explain the dose-response correlation for VWF.

A first tentative to modify the weighting filter W_h has been proposed by WG 3 of ISO/TC 108/SC4, but it is quite hard to modify now the W_h weighting curve, because it is used in standards and legislative texts (Liedtke et al., 2013).

A new supplementary curve with a flat frequency range between the cut-off frequency of 200 Hz and 400 Hz is under discussion. It should be noted that this threshold range pertains only to the risk of developing vascular hand-arm vibration injury (Brammer and Pitts, 2012).

All these studies tried to clarify the relationship between impulsiveness level and responses of finger blood flow and nerve disease to work out the proposal for appropriate evaluation methods for the future development of exposure risk criteria.

5. Conclusions

In this work the vibration produced by three beaters used by ten operators in idling condition and during the olive harvesting campaign were acquired and analysed.

Their vibration total values were high in both idling and full load conditions, but especially in the latter and at the front hand position the acceleration were never lower than 20 ms^{-2}.

The exposure to the hand-arm vibration is nowadays evaluated through the ISO 5349-1 standard, based on the vibration measurement using the frequency weighting W_h, which heavily cut the acceleration data at the medium and high frequencies: as a consequence there is the hazard to underestimate the hand arm vibration risk when using some machines, as the beaters, which produce high acceleration values at the medium/high frequencies.

For this reason we used also the W_{h-bl} filter (as explained in the ISO/TS 15694 standard) to obtain flat weighted acceleration and to verify if impact and shocks events were present.

In all the examined beaters high differences were found between the W_{h-bl} flat weighted and the W_h weighted acceleration values: their averaged ratio was never less than 2.

The frequency analysis of the flat weighted signal in this work was also useful to define the vibration behaviour of the beaters. In fact, the tested beaters had a similar harvesting volume rate (about 120 kg/h of olives), but they had a different vibration behaviour. The hand arm system of the operator using the beater #3 was solicited to acceleration values in the frequency range 63-1200 Hz, higher than the other two examined beaters. This information may be useful for the manufacturer to redesign the machine.

Moreover, this work demonstrated that the hand held olive beaters may produce high impulsive loads: in fact the crest factor values ranged from 5 to more than 22, comparable to the industrial hand held tools.

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