Transmission of vibrations from portable agricultural machinery to the Hand-Arm System (HAV): risk assessment and definition of exposure time for daily action and exposure limits

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Abstract

Every day agro-forestry workers are exposed to health and safety risks, due to work environment and the machineries they use.
Some of these risks, vibrations for example, are usually underestimated by workers as well, because vibrations do not represent an immediate risk for the health.
The vibrations can cause some professional diseases whose symptoms can appear after many years too. This is not a good reason to ignore the problem; in fact the consequences of a long exposure time can be very serious.
A deeper knowledge of diseases caused by vibrations, laws, the best precautions and safety systems can represent a start to limit the phenomenon.
The research about agro-forestry machineries can represent a stimulus to use ergonomic instruments in order to guarantee the health and the safety of the workers.
The present research aims to highlight the importance of the exposure to vibrations in agro-forestry sector and its consequences on human health, above all the risks for the hand-arm system during the working day.
Every machine has been directly analyzed to establish the level of vibrations produced according to the laws in force and the most recent ISO norms.
With the collected data it was possible to establish the maximum exposure times for every instrument in order to respect the European Directive 2002/44/CE of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibrations).

Keywords: health at work, hand harm vibrations, portable instruments.

Introduction

Agro-forestry workers are exposed to many types of risks. 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. However, this is not a reason to ignore the problem as the consequences of being exposed to extended vibrations can be rather serious. To this day, all the possible implications related to the exposure of human body to vibrations are still not totally clear. In order to formulate biomechanical models operative for the definition of appropriate criteria of risk assessment , it is necessary to understand the influence between the physical parameters of the vibrations and the physiological ones of the exposed organism.

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. The aim of this paper is to give a contribution to vibration risk assessment deriving from the utilization of portable equipment, which is largely used in this sector. More specifically, we refer to the assessment of the risk for the hand-arm system at which operators are exposed during the working phases. The assessment has been done trough direct measurement, using the adequate equipment to record the vibrometric levels of each analyzed machine. Above all, six models of shoulder portable blowers, four brush-cutters, one chainsaw and one hedge cutter have been analyzed. The procedure has been carried out following all legal provisions and the most recent ISO standards. The data elaboration deriving from this survey has permitted to check if the models respect the requirements of the European Directive 2002/44/CE.

Material and methods

Legal framework

The European Directive 2002/44/CE on the minimum health and safety requirements regarding the exposure of workers to the risks arising from vibrations is characterized by a set of basic and fundamental obligations to preserve the safety of workers exposed to mechanical vibrations. These obligations are consolidated by the European legislation also for other risk factors. More specifically, two exposition indicators for the vibrations transmitted to the hand-arm system have been identified: the action value and the exposure limit value (table 1). The overcoming of these two values lead to a set of obligations. The daily exposure action value on the hand-arm system, standardised to an eight hour reference period, A(8) shall be 2,5 m/s^2 r.m.s., while the daily exposure limit value, standardised to an eight-hour reference period, shall be 5 m/s^2 r.m.s.

Table 1. Daily action and exposure limit values transmitted to the hand-arm system standardised to an eight hour reference period

VIBRATIONS TRANSMITTED TO THE HAND-ARM SYSTEM	
Level of daily exposure action value A(8) = 2,5 m/s^2	Daily exposure limit value A(8) = 5 m/s^2

The action value represents that value of daily exposure from which specific measures for the protection of exposed workers must be implemented (e.g. training about the specific risk, intervention aiming at risk reduction, periodic health control for exposed workers), while the limit value represents the level of exposure that cannot be exceed (because it involves an inacceptable risk for an individual exposed to vibrations without the adequate protections). In relation to the exposure to vibrations transmitted to the hand-arm system, the European Directive fixes as prevention reference levels (action and exposure limit values) the same values indicated by the specialized technical literature, and therefore it defines:

- limited risk situations (A(8) < 2,5 m/s^2); exposures for which maintaining the general attention is enough (for instance, the medical control of workers that declare problems related to vibration exposure transmitted to the hand-arm system or the purchasing of specific equipment able to transmit lower values of vibrations, etc.);
- intermediate situations between the level of action and the exposure limit values (that is 2,5 m/s^2 < A(8) < 5,0 m/s^2), which determine the need of intervention, the editing of a bonification programme and the health monitoring;
- high risk situations (A(8) > 5,0 m/s^2) that determine an immediate intervention through the introduction of intervals of the exposed workers or the utilization of appropriate IPD (individual protection devices), while waiting for the implementation of technical interventions in order to bring the exposure conditions to values lower than A(8) = 5,0 m/s^2.

Reference ISO standards for vibrations transmitted to the hand-arm system

The assessment of the vibration exposure level transmitted to the hand-arm system is mainly based on the determination of the value of daily exposure standardised to an eighthour reference period, A(8) (m/s^2), estimated on the base of the root of the sum of the squares ($A_{(W)sum}$) 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 (2001) standard [3]. The equation to calculate A(8) is the following:

$$A(8) = A_{(w)sum} \, (Te/8)^{1/2} \quad (1)$$

where:

Te : total daily vibration exposure (hours);

$A_{(w)sum}$: $(a^2_{wx} + a^2_{wy} + a^2_{wz})^{1/2}$;

a_{wx} a_{wy} a_{wz}: r.m.s. values of frequency-weighted acceleration (m/s^2) on the *x*, *y*, *z* axes.

The EN ISO 5349 standard "Mechanical vibration. Measurement and evaluation of human exposure to hand-transmitted vibration" is divided in two parts: the EN ISO 5349 – 1 and the EN ISO 5349 – 2. The EN ISO 5349 – 1 "Part 1: General requirements" specifies the general requirements for the measurement and the record of the exposure to mechanical vibrations transmitted to the hand on the three orthogonal axes (*x*, *y*, *z*). It defines the weighting frequency and the band filters in order to obtain a uniform and standardized comparison of the measurements. The obtained values can be utilized to calculate the negative effects of the vibrations transmitted to the hand for the octave band 8Hz-1.000 Hz frequency interval. Furthermore, as it is shown in figure 1, the normative defines the Cartesian axes system. The orthogonal reference system starts at the head of the third metacarpal segment, being the *z* axis parallel to the hand axis, the *y* axis perpendicular to the plan delimited by the *x* and *z* axes with a right-left orientation.

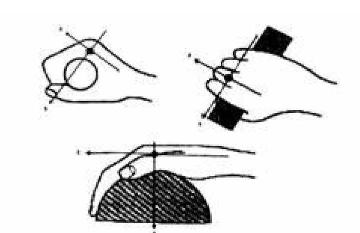

Figure 1. Definition of the measurement axes (ISO 5349)

The EN ISO 5349 standard – "Part 2: Practical guidance for measurement at the workplace" describes the cautions to be adopted in order to obtain representative measurements of vibrations and to determine the daily exposure to each operation with the aim of calculating the total value of vibration standardised to an eight hour reference period, A(8), according to the principle of the equal energy (daily exposure to vibration). In addition, the normative gives the means to determine all the relevant operations that should be taken into account when evaluating vibration exposure. The normative is valid for all situations in which persons are exposed to vibrations transmitted to the hand-arm system from portable machinery, manual guiding machines, vibrating tools or control devices of mobile or stationary machinery [4].

Data collection equipment

To measure the hand-arm system vibrations, instruments of different constructors have been used. More specifically, to detect the accelerations on the 6 models of blowers it has been used the Brüel & Kjær measuring chain, which consists in a 4506 Deltatron® 3 axes accelerometer and in a 1700 model 3 channels interface for human vibrations that has the function to amplify and transmit the signal to the measuring device made of a 2260 Investigator integrating sound level meter. All the other measurements have been done utilizing the Larson Davis SEN020 3 axes ICP accelerator connected to the 3 axes HVM-100 vibration measuring equipment. This instrument is more manageable than the previous one because it is smaller and lighter; furthermore, it can measure at the same time the vibrations on the three axes *x*, *y* and *z* and the relative vector sum. The utilized analysers have the rating certificate and satisfy all requirements the instrumentation type 1 stated by the CEI EN 61672-1-2 (former IEC 804). Before doing the measurements, all instruments have been rated using generators of sinusoidal vibration that provide a known pick acceleration (10 m/s^2 r.m.s.) at a given frequency (159,2 Hz). During each set of measurements, a stimulating calibrator has been applied to the accelerometer in order to verify the calibration of the entire measuring system on the three axes (*x*, *y*, and *z*) of the accelerometer. The utilized accelerometers have been firmly fixed on the handle of the machine, close to the hands of the operator, but not affecting the normal course of action. To fix the accelerometers on the machines, specific adaptors with two plastic bands have been utilized; while the accelerometer cables, in order to avoid distortions in the measured signal or eventual damages, have been fixed near the transducer with adhesive tape.

Characteristics and place of measurement

During the experimental phase of this survey, the sums of squares ($A_{(W)sum}$) of the root mean square value of the frequency-weighted accelerations have been measured with the appropriate instrument. These values, as is shown in the formula (1), calculated for an exposure time of Te = 8 hours correspond to the daily exposure values standardised to an eight-hour reference period A(8). However, since we have noticed that in the chosen farms, due to refuelling and interruptions, it is rare to reach eight working hours per day with the machines always on, it is more correct to consider a total vibration exposure time of seven hours (Te = 7 hours). Thus, in order to test a more realistic level of exposure for the operators, the respective A(8) referred to 7 hours of exposure have been calculated. Therefore, the formula (1) becomes:

$$A(8) = A_{(w)sum} \ (7/8)^{1/2} \qquad (2)$$

To make the measurements repeatable, it has been necessary to equalize the maintenance conditions of the machines. Before the experimental tests, all air and fuel filters have been cleaned and the spark plugs have been checked. Furthermore, all machines have been refuelled with the same kind and amount of fuel. The measurement of the vibrations given off by the shoulder portable blowers has been carried out during the hazelnut harvest in some farms located in the Monti Cimini area (central Italy). The acceleration values of the other portable equipment have been gained at the Faculty of Agriculture of Tuscia University, and more specifically at the botanical garden and the corporate didactic trial. The tests have been carried out during the regular working activity. In all machines, in correspondence with each measurement point and for each axes, the values of three samples have been first recorded and then averaged to obtained a single level of acceleration for each axes *x*, *y* and *z*. The EN ISO 8041:2005 standard, which defines the metrological method for the vibration measurement equipment, states that in order to reduce the error, it is proper to record a sample of at least 20 seconds [5].

Results

In table 2, all the accelerations related to the hand-arm system and measured directly are shown. For each column are respectively indicated the A(8) values referred to a seven hours exposure period and $A_{(w)sum}$ .For those machines held with both hands are indicated the values related to each limb, while for the blowers the measurements refer only to the right hand because the left one is not used. In any case, the calculation of the daily exposure level has been done considering the higher value.

Table 2. Hand-arm system vibration's values

Hand-arm system HAV					
Model		Operative conditions	$A_{(w)SUM}$ (m/s^2)		A (8) ref. T_e = 7 h (m/s^2)
			L	R	
1	**Blower Echo PB 6000**	working load	**N.R.**	**2,57**	2,40
2	**Blower Zenoah Komatsu EB 7000**	working load	**N.R.**	**2,60**	2,43
3	**Blower Shindaiwa EB 630**	working load	**N.R.**	1,27	1,19
4	**Blower Shindaiwa EB 8510**	working load	**N.R.**	1,99	1,86
5	**Blower Shibaura KB 60**	working load	**N.R.**	**4,22**	**3,95**
6	**Blower Efco SA 2062**	working load	**N.R.**	**4,71**	**4,41**
7	**Chainsaw Stihl Ms 250**	working load	**6,07**	**4,13**	**5,68**
8	**Hedge cutter Stihl Hs 85**	working load	**6,17**	**4,23**	**5,77**
9	**Brush cutter Efco SA 2062**	working load	**4,84**	**4,01**	4,53
10	**Brush cutter Echo srm-4605;**	working load	**4,62**	**3,83**	4,32
11	**Brush cutter Stihl Fs 250**	working load	**4,22**	**3,38**	**3,95**
12	**Brush cutter Shindaiwa Sk 45 F**	working load	**4,38**	**3,85**	**4,10**

As it is notable from the table, the machines indicated with the numbers 1, 2, 3 and 4 give off an acceptable hygienic level of vibrations. Indeed, the A(8) values referred to T_e = 7 h do not exceed the prevention values defined by the 2002/44/EC directive. More specifically, the Echo PB 6000 blower has a level of 2,40 m/s^2, Zenoah Komatsu EB 7000 of 2,43 m/s^2, Shindaiwa EB 630 of 1,19 m/s^2 and Shindaiwa EB 8510 of 1,86 m/s^2. The first two models are slightly under the limit of 2,5 m/s^2 fixed by the normative. Anyhow, these two machines have a $A_{(w)sum}$ level that correspond to the A(8) referred to 8 hours of exposure, just above the action level. In addition, it is important to notice that the A(8) values calculated for the Shindaiwa blowers do not reach any action limit and therefore, even for those working activities that take height hours, the Shindaiwa model guarantees the not overcoming of the limits imposed by law. The models 5, 6, 9, 10, 11 and 12, even if not overcoming the limit values of daily exposure and thus not representing a high risk situation, expose the operators to vibration levels higher than the action value. More specifically, the Efco SA 2062 blower with 4,41 m/s^2, the Efco SA 2062 brush cutter with 4,53 m/s^2 and the Echo srm-4605 brush cutter with 4,32 m/s^2 have high values that concerning prevention and health at work should be taken into consideration. The vibrations given off by the machines number 7 and 8 (Stihl Ms 250 chainsaw with 5,68 m/s^2 and Stihl Hs 85 hedge cutter with 5,77 m/s^2) correspond to A(8) values greater than the daily exposure limit value. 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 [1 - 2].

Daily duration of exposure

To make the employers able to organize adequate work schemes, respecting the health of the worker, the maximum daily duration of exposure for each machine has been calculated (table 3). To be more precise, the time needed to reach the limits defined by the 2002/44/EC directive in one day by a single worker it has been evaluated as follow:

- the daily duration of exposure to the action value (Ta), that is the time that a worker needs to reach the action threshold (A(8) = 2,5 m/s^2 HAV): $Ta = [A(8)^2/a_{hw}^2] \cdot 8$;
- the daily duration of exposure to the limit value (Te), that is the time that a worker needs to reach the limit value of exposure (A(8) = 5 m/s^2 HAV): $Te = [A(8)^2/a_{hw}^2] \cdot 8$.

Table 3. Exposure time to the action value and the daily limit

Model		a_{hw} [1] (m/s^2)	Daily duration of exposure to the action value (h)	Daily duration of exposure to the limit value (h)
1	Blower Echo PB 6000	2,57	7,57	24,00
2	Blower Zenoah Komatsu EB 7000	2,60	7,40	24,00
3	Blower Shindaiwa EB 630	1,27	24,00	24,00
4	Blower Shindaiwa EB 8510	1,99	12,63	24,00
5	Blower Shibaura KB 60	4,22	2,81	11,23
6	Blower Efco SA 2062	4,71	2,25	9,02
7	Chainsaw Stihl Ms 250	6,07	1,36	5,43
8	Hedge cutter Stihl Hs 85	6,17	1,31	5,25
9	Brush cutter Efco SA 2062	4,84	2,13	8,54
10	Brush cutter Echo srm-4605;	4,62	2,34	9,37
11	Brush cutter Stihl Fs 250	4,22	2,81	11,23
12	Brush cutter Shindaiwa Sk 45 F	4,38	2,61	10,43

The limit daily duration of exposure, so that the machines can be utilized without overcoming the A(8) limit value are shown in figure 2. It is evident that these durations plenty overcome the seven hours working period, which is the usual working period for an operator. Only in two cases the operators could reasonably reach the limit value defined by law: with the Stihl Ms 250 chainsaw (n.7) if the worker would be exposed more than 5,43 hours and with the Stihl Hs 85 hedge cutter (n.8) in case of duration of exposure greater than 5,25 hours.

[1] The ahw values correspond to the $A_{(W)SUM}$ acceleration values.

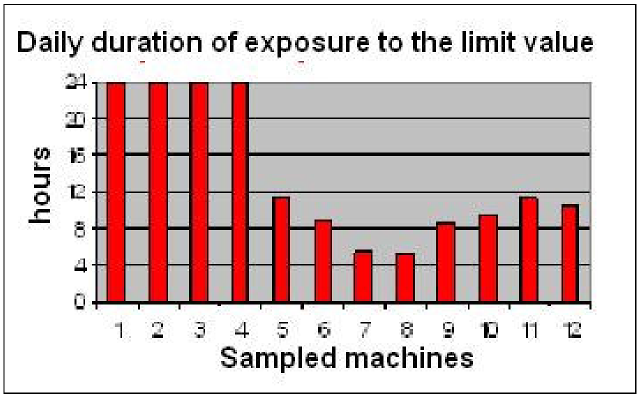

Figure 2. Limits of daily duration of exposure

On the other hand, the remarks on the daily duration of exposure to the action limit (figure 3) are quite different. Indeed, only for the Echo PB 6000 (n.1), the Zenoah Komatsu EB 7000 (n. 2), the Shindaiwa EB 630 (n. 3) and the Shindaiwa EB 8510 (n. 4) blowers there are no risks of reaching the action value in the seven hours working period, since their limit duration at action are 7,57, 7,40, 24,00 and 12,63 hours respectively. For all the other models, the action level is reached within the working day. The action times of the Shibaura KB 60 (n. 5) and the Efco SA 2062 (n. 6) blowers (2,81 and 2,25 hours respectively) are very similar to those of the four brush cutters (n. 9-10-11-12). For the other two remaining models, the chainsaw (n. 7) and the hedge cutter (n. 8), the caution level is rapidly reached: for the first machine after 1,36 hours and for the second one after only 1,31 hours.

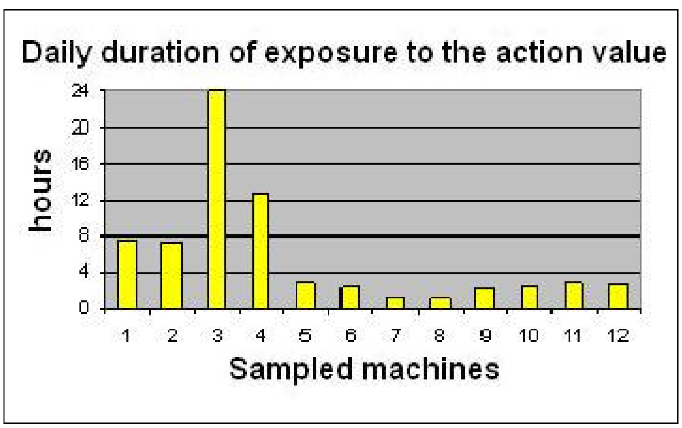

Figure 3. Daily duration to the limit action value

Conclusions

The present research, evaluating the risk to the hand-arm system due to vibrations, has given an overview of the risks to which operators are exposed when using these machines. In order to make a correct assessment, all the laws and the standard normative about this issue have been taken into account. More specifically, we referred to the 2002/44/EC directive, which defines all the specific requirements regarding the exposure of workers to the risks arising from mechanical vibrations, and to the ISO 5349 standard that gives details for the hand-arm system. All the acceleration levels standardised to an eight hour reference period but referring to a seven hour exposure period (A(8) ref. 7h Te) have been recorded. In order to verify if the sampled models respond to the safety requirements, the obtained data have been compared with the prevention values fixed by the normative. The vibration levels given off by the machines and measured during the real working conditions, in some cases do not respect the actual normative. Still, significant differences can be noticed among the models. The best machines from an hygienic point of view are the Shindaiwa EB 7000 and the Shindaiwa EB 630 blowers, for which has been recorded a A(8) ref. 7h value lower than the action limits. The Echo PB 6000 and the Zenoah Komatsu 7000 models expose the workers to low action values, but if we consider a working day of 8 hours the action limit is overcame reaching 2,57 and 2,60 m/s^2. The Shibaura KB 60 and the Efco SA 2062 blowers, as well as the four brush cutters, expose the workers to levels greater than the action ones. In any case, the worst result from a hygienic point of view comes from the chainsaw and the hedge cutter. Indeed, the vibration levels given off by these machines overcome the limit value. In conclusion, for the hand-arm system exposure, the study has shown low ($A(8) < 2{,}5\ m/s^2$), intermediate ($2{,}5\ m/s^2 < A(8) < 5{,}0\ m/s^2$) and high ($A(8) > 5{,}0\ m/s^2$) risk situations.

References

[1] Decreto Legislativo n.187 del 19 agosto 2005, Attuazione della direttiva 2002/44/CE sulle prescrizioni minime di sicurezza e di salute relative all'esposizione dei lavoratori ai rischi derivanti da vibrazioni meccaniche, Gazzetta Ufficiale n. 220 del 21 settembre 2005

[2] Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC).

[3] UNI EN ISO 5349-1:2001 "Mechanical vibration - Measurement and evaluation of human exposure to hand- transmitted vibration - Part 1: General requirements"

[4] UNI EN ISO 5349-2:2001 "Mechanical vibration - Measurement and evaluation of human exposure to hand- transmitted vibration - Part 2: Practical guidance for measurement at the workplace"

[5] EN ISO 8041:2005 "Human response to vibration - Measuring instrumentation"

The contribution to the programming and executing of this research must be equally divided by the authors.