HAND-ARM VIBRATION IN DIFFERENT OPERATING CONDITIONS WITH A CHAINSAW

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Resumo

Vibração em mãos e braços para diferentes condições operacionais com motosserra. A mecanização da colheita florestal é uma tendência em nosso País. Contudo as pequenas e médias empresas do setor florestal, ainda hoje, optam pela colheita semimecanizada, utilizando motosserras para a colheita e seccionamento de árvores. Apesar dos avanços tecnológicos, as motosserras quando operadas continuamente, podem causar danos ao corpo do operador atuando como agente estressor sendo que o excesso de vibração é responsável por inúmeros distúrbios, dentre estes a síndrome de *Raynoud*. Neste sentido, o presente trabalho teve por objetivo determinar o nível de vibração ao qual é submetido um operador de motosserra, durante o corte transversal (traçamento) da madeira, em diferentes espécies florestais e conjuntos de corte. Os tratamentos consistiram de três espécies florestais (*Eucalyptus grandis*, *Eucalyptus dunnii* e *Acácia mearnsii De Wild)* e dois conjuntos de corte constituídos por correntes de dentes dos tipos semi-quadrado e quadrado. A avaliação da vibração baseou-se nos critérios estabelecidos pela Norma Regulamentadora NR15, NHO10 e ISO 2631-4. Os resultados dos níveis de vibração foram superiores aos limites de referência estabelecidos pela Norma ISO 2631-4, sendo que para ambos os conjuntos de corte, os maiores níveis de vibração ocorreram no eixo “x”. Após o processamento dos dados, os valores de aceleração resultante da exposição normalizada para as vibrações de mãos e braços apresentaram diferenças significativas para os eixos “y” e “z”. Portanto, pode-se inferir que a operação com motosserra é um agente estressor, potencialmente capaz de gerar danos à saúde dos trabalhadores.

Palavras-chave: Saúde ocupacional, Acelerômetro, Agente estressor.

Abstract

The mechanization of forest harvesting is a trend in Brazil. However, small and medium-sized companies in the forestry sector, even today, opt for semi-mechanized harvesting, using chainsaws for the harvesting and sectioning of trees. Despite technological advances, when operated continuously, chainsaws may cause damage to the operator’s body, acting as a stressor, and vibration excess is responsible for numerous health disorders, among them the *Raynaud* syndrome. In this sense, this study aimed to determine the vibration levels to which a chainsaw operator is subjected, during the transversal cut (tracing) of the wood, in different forest species and cutting sets. The treatments consisted of three forest species (*Eucalyptus grandis, Eucalyptus dunnii* and *Acacia mearnsii De Wild)* and two cutting sets, consisting of square tooth chains of the semi-chisel and chisel types. The vibration assessment was based on the criteria established by the Regulatory Standards NR15, NHO10 and ISO 2631-4. The results of vibration levels were higher than the reference limits established by ISO 2631-4, and, for both cutting sets, the highest vibration levels occurred on the “x” axis. After the data processing, the acceleration values resulting from the normalized exposure to hand-arm vibrations showed significant differences for the “y” and “z” axes. Therefore, it can be inferred that the chainsaw operation is a stressor, potentially capable of causing damage to workers' health.

Keywords: Occupational health and safety, Accelerometer, Stressor.

INTRODUCTION

Chainsaws are important machines for forestry cutting operations. In many cases, the use of the chainsaw is indispensable due to the slope of the terrain, which does not allow mechanized cutting operations to be carried out. Ottonelli *et al.* (2020) highlight that chainsaws are versatile machines and have a wide range of possibilities for domestic, agriculture and forestry use. Despite the versatility and importance of chainsaws, they can act as health stressors, as well as they may compose a group of ergonomic factors. The main occupational exposures that chainsaw operators are subjected to are: physical risks (noise and vibration) (ROTTENSTEINER and STAMPFER, 2013; JESUS *et al.*, 2020); ergonomic risks (intense physical effort, manual weight lifting and carrying, inadequate posture, excessive rhythms, prolonged working hours, repetition); accident risks (poisonous animals and falling of branches) and; still, the gases emitted by the exhaust system (ALANDER *et al.*, 2010).

Exposure to vibration can have a harmful effect on the safety and health of human beings. Iida (2005) points out that vibration comprises any movement that the body performs around a fixed point, which can be regular, sinusoidal, or irregular, when it does not follow any determined pattern. Corroborating this view, Kroemer end Grandjean (2005) describe that the human body presents a natural vibration, and for this reason most of the activities carried out on a daily basis present some level of vibration. In the case of machines, the authors Balbinot (2001) and Saliba *et al.* (2002) highlight that vibration is associated with imbalances, tolerances and gaps in the different constituent parts. It is important to highlight that vibration is derived from the operation of the engine, due to the intermittency of combustion.

Localized vibrations are those that can somehow reach certain parts of a body, mainly hands and arms, in a frequency range from 6.3 to 1250 Hz, being present, for example, in oscillatory hand tools (GOMES; SAVIONEK, 2014). According to Rottensteiner and Stampfer (2013) Hand-Arm Vibration (HAV) is transmitted to the body through the contact surface between hands and the equipment. Furthermore, depending on its frequency and amplitude, its direction and time of exposure, vibration can cause serious damage to the worker's health and well-being.

The main effects caused by HAV may be of vascular, neurological, osteoarticular and muscular order (GRIFFIN *et al.*, 1998; SALIBA *et al.*, 2002). Continuous exposure to HAV produces a set of symptoms known as the *Raynaud* syndrome, also called the white finger syndrome. This phenomenon occurs due to the reduction of blood flow, mainly in extremities, such as hands and feet and, in a reduced way, in ears, tongue and nose (VENDRAME, 2016).

In order to measure and evaluate the degree of vibrations in the human body, there are national and international standards that present the admissible acceleration values during the work shift. If the value stipulated by a certain standard is exceeded during the performance of the task, this work environment is considered insalubrious.

The standards establish tolerable limits for efficiency, safety and comfort. The vibration parameters are universally measurable in metric units, usually expressed in meters per second squared ($m\ s^{-2}$) as defined in standards ISO 5349:1 (2001), ISO 5349:2 (2001), ISO 2631-4 (2001), NHO10 (2013). The measurement follows a coordinate system divided into the orthogonal (biodynamic) axes x, y and z, originating at a point, at the interface between the vibrating source and the body.

Currently, the Directive 2002/44/EC, of the European Parliament, issued on June 25th, 2002, has been in force. It sets numerical and fixed values for vibration limits, both for whole-body vibration and for hand-arm system vibration. They are specified in Exposure Limit Value (ELV) and Exposure Action Value (EAV), both for a daily exposure of 8 hours.

As it is described by Iida (2005), it is necessary to understand the physical interactions between the worker and his workstation involving machines, tools and materials, with the objective of reducing the risks of muscular and skeletal disorders. This way, the vibration levels to which chainsaw operators are exposed to during forest cutting operations, under different operating conditions and forest species, need to be better studied. Corroborating the above, Rottensteiner and Stampfer (2013) emphasize the need to carry out experiments and studies on vibration in the operation of chainsaws. The authors identified a relationship between vibration and the operation, however, a deep analysis of the consequences of exposure to this physical agent as an organizational stressor was not exposed. In this sense, the present study aimed to determine the level of vibration to which a chainsaw operator is subjected during the transversal cut of the wood, in three forest species and with two cutting sets.

MATERIALS AND METHODS

Characterization of the studied area

This research was carried out in an area with stands of *Eucalyptus grandis* Hill ex-Maiden, *Eucalyptus dunni* Maiden and *Acacia mearnsii* De Wild, in the experimental area of the State Foundation for Agricultural Research - FEPAGRO FLORESTAS, located in the municipality of Santa Maria, in the State of Rio Grande do Sul, coordinates of 29°30' latitude S 54º15' longitude W of Greenwich, with an average altitude of 113 meters. The soil of the studied area is classified as Arsenic Red-Yellow Dystrophic Arenic (EMBRAPA, 2006; STRECK *et al.,* 2008), belonging to the São Pedro Mapping unit.

According to Köppen's classification, the climatic characteristics in the region of the studied area fall into the "Cfa" type classification (humid subtropical), with an average annual temperature of 19.2 °C, and average annual rainfall varying from 1,322 to 1,769 mm year- 1 (ALVARES *et al.*, 2013).

Description of the cutting sections

The experiment consisted of wood sections with one meter in length from three forest species (*E. grandis, E. dunnii* and *A. mearnsii),* and the use of a new chainsaw and two cutting sets (tooth chain, guide bar and chain sprocket). The used chains were composed of the square tooth semi-chisel (which is used for jobs of less intensity, due to be more easily sharpened and presenting a lower tendency to kickback); and square tooth full chisel (which are used in professional chainsaws, due to its higher performance).

To perform the cross-sectional cuts (tracing) it was used a chainsaw with 2.6 kW power, 4.8 kg mass and an engine with a displaced volume of 50.2 cm³, intended for semi-professional jobs of lesser intensity.

The cross-sectional cuts were performed following the recommendations of standard ABNT NBR ISO 22867 (2018). Each section of standardized wood, 0.30 meters in diameter, was positioned on an easel with a height of 0.60 m in relation to ground level. Afterwards, it was performed the cutting of transversal discs measuring 0.05 m of thickness (Figure 1 A and B), according to the methodology proposed by Kovác *et al.* (2018). The cutting and sectioning of the wooden discs were carried out by the same operator, 1.76 meters tall with a body mass of 86 kg, in order to guarantee the repeatable cutting technique, throughout the whole data collection.

Figure 1. Marking the thickness of each disc (A); sectioning the discs and collecting hand-arm vibration data (B).
Figura 1. Marcação da espessura de cada disco (A); seccionamento dos discos e coleta dos dados de vibração de mãos e braços (B).

As recommended by standard ISO 5349-1 (2001), vibration levels were collected during the use of the chainsaw, by means of an accelerometer positioned on the right hand grip handle, close to the throttle trigger (Figure 2 A). In addition, for the acquisition of the data on localized vibration magnitude, it was used a portable analyzer, brand Brüel and Kjaer, model 4447 (Figure 2 B), which allows to measure the vibration values in the three orthogonal axes (x, y and z) in the range from 1 to 80 Hz (Figure 2 C).

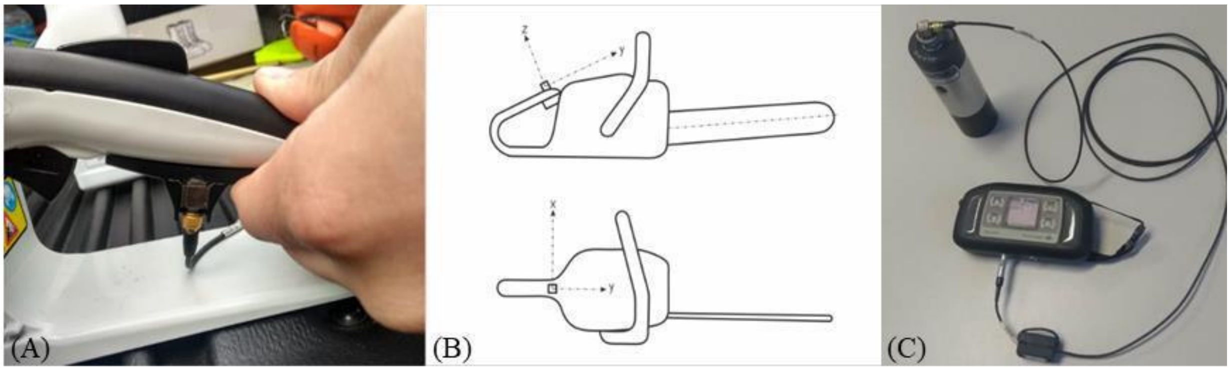

Figure 2. Positioning of the accelerometer on the right hand grip handle (A); Exemplification of the three orthogonal axes on a chainsaw for measuring vibration, adapted from Rottensteiner and Stampfer (2013) (B); Portable analyzer with the calibrator used to collect vibration levels (C).
Figura 2. Posicionamento do acelerômetro no cabo de empunhadura da mão direita (A); Exemplificação dos três eixos ortogonais em uma motosserra para mensuração da vibração, adaptado de Rottensteiner e Stampfer (2013) (B); Analisador portátil com o calibrador utilizado na coleta dos níveis de vibração (C).

Based on the standard NHO 10, the safety interval was defined in the range that varies between 4 and 8 hours of daily exposure, which represents the working hours of most workers. The maximum weighted acceleration established by this standard is 1.25 m s^{-2} for a 4-hour exposure period, and between 0.82 and 0.90 m s^{-2} for an 8-hour exposure period.

$$a_{v=}\sqrt{K_x^2\, a_{wx}^2 + K_y^2\, a_{wy}^2 + K_z^2\, a_{wz}^2} \tag{1}$$

in which: a_{wx} a_{wy} a_{wz} = weighted effective accelerations, of the orthogonal axes x, y and z, respectively; K_x K_y K_z = multiplication factors that have the values (K_x; K_y = 1.4; and K_z = 1.0) respectively.

The combined acceleration in the three axes was obtained by equation 2.

$$a = \sqrt{1{,}4a_x^2 + 1{,}4a_y^2 + a_z^2} \tag{2}$$

in which a_x a_y a_z = weighted effective accelerations, of the orthogonal axes x, y and z, respectively.

The Regulatory Standard No. 15, in its Annex No. 8 (BRAZIL, 2018), indicates that all limits of exposure to vibration are defined by the standards ISO 2631-4 and ISO 5349. For the assessment, the daily duration of T exposure should be considered, in hours, being the total period of time that the individual is exposed to the given situation during a day. Daily exposure to vibration A (8), in m s^{-2} (Equation 3).

$$A(8) = a_{v;}\sqrt[e]{\frac{T}{T_0}} \tag{3}$$

in which: $a_{v,e}$ = is the total equivalent vibration in m s^{-2}. T = duration period of daily working hours, expressed in hours or minutes. T_0 = reference duration period of 8 hours or 480 minutes.

The standard ISO 5349 (2001) does not provide safety limits for the exposure to hand-arm vibrations, but it does provide a time estimate for the appearance of the white finger pathology (Reynaud's Syndrome), which associates the value of A (8) with time, for a group of 10% of people (Figure 3).

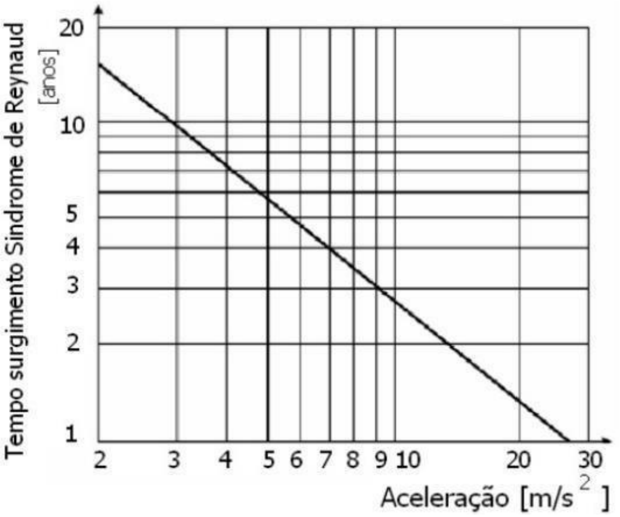

Figure 3. Relationship between A (8) and time for the appearance of Raynauld's syndrome.
Figura 3. Relação de A(8) e tempo de aparecimento da sindrome de Raynauld.
Source: ISO 5349 (2001).

It was used a completely randomized design, in a bifactorial arrangement (two cutting sets and three forest species), with 10 repetitions. The values of the analyzed variables were submitted to the Shapiro-Wilk test to verify the normality of the data, and to the Bartlett test, to verify the homogeneity of the variances. When non-normality was observed, the data were subjected to the Kruskal-Wallis nonparametric test with multiple comparisons through the Bonferroni method. The tests were applied with the software ACTION Stat 3.7.

RESULTS

In different operating conditions with the chainsaw, the performance resulting from the acceleration of maximum and minimum vibration on hands and arms, in different orthogonal axes wx, wy, wz for cutting sets A and B, for species *A. mearnsii*, *E. dunnii* and *E. grandis*, are presented in Table 1.

Analyzing the amplitude of variation of the acceleration between the orthogonal axes, for the species and cutting sets used, the highest values were observed in the "x" axis. Furthermore, it is noteworthy that the greatest variation in amplitude, of 3.75m^{-2}, was observed for species *A. mearnsii* with cutting set B, on the "x" axis, exceeding the action level established by NR15. For the species *E. dunni*, the greatest variation in amplitude was observed in the "x" axis, with 2.91m^{-2}, also with cutting set B. As for the species *E. grandis*, the greatest variation in amplitude was observed on the "x" axis, with 2.15m^{-2}, for cutting set A.

Table 1. Variation of localized vibration acceleration in a chainsaw operator for the different cutting sets and forest species.

Tabela 1. Variação da aceleração de vibração localizada em operador de motosserra para os diferentes conjuntos de corte e espécies florestais.

		Maximum and minimum variation in acceleration in m s^{-2}					
Forest Species	**A**	**Cutting set A**			**Cutting set B**		
		wx	**wy**	**wz**	**wx**	**wy**	**wz**
Acacia mearnsii	10	5,78 ± 3,51	2,94 ± 0,85	2,83 ± 1,14	5,31 ± 1,56	3,26 ± 0,93	2,22 ± 0,70
Eucalyptus dunnii	10	4,88 ± 2,27	1,58 ± 1,02	3,47 ± 0,92	4,82 ± 1,91	1,69 ± 0,85	3,42 ± 1,45
Eucalyptus grandis	10	5,61 ± 3,46	1,69 ± 1,10	2,45 ± 1,20	5,37 ± 3,87	1,70 ± 1,32	3,21 ± 1,22

A = number of samples.

It is noteworthy that the maximum acceleration value, on the "x" axis for all evaluated species, for both assessed cutting sets, exceeded the tolerance limit of 5.0 m s-^{2}, established by NR15 and NHO10. This way, the importance of using PPE's and taking rest breaks during the workday becomes evident. Regarding the "y" and "z" axes for the two cutting sets, the tolerance limit was not exceeded.

The variation in the mean vibration acceleration for cutting sets A and B, for the species *E. dunnii*, presented a behavior similar to that of species *A. mearnsii,* with the highest measured values on the orthogonal "x" axis. For this species and used cutting sets, the mean acceleration levels in the three orthogonal axes did not exceed the tolerance limit of 5.0 m s^{-2}.

Comparing the two cutting sets A and B for the species *E. grandis*, the acceleration levels were within the permitted values for the orthogonal axes y and z, but exceeding the value for action level established by NHO10 on the "x" axis. The greatest variations predominated on the "z" axis for both cutting sets, due to the direction of the "z" axis, which faces the operator's body (arm) towards the cutting set in the longitudinal direction (causing greater oscillation in the acceleration transmitted to the operator's body).

The values referring to the mean accelerations of vibrations, for the three orthogonal axes during the sectioning of the discs, considering the different cutting sets and forest species, are presented in Figure 4.

The difference in acceleration between the cutting sets was 7.8% referring to the "x" axis, in which the values were considered high when compared to the action level established by NHO10. When analyzing the acceleration individually for each species, *A. mearnsii* presented a higher level of vibration with the cutting set A on the "x" axis, representing 81.54% of the resulting acceleration. This result can be explained by the direction that the cutting set was positioned, in this case, downwards, in the same direction that the operator performed the cutting of the discs.

For the species *E. dunnii*, the highest level of vibration occurred with cutting set B on the "x" axis. It was observed that for cutting set A, on the "x" axis, the values were high as well as for B. However, the difference in acceleration between the cutting sets was small, resulting in only 15%. This way, it was possible to infer that both cutting sets transmitted similar levels of vibration and within what is permitted considering standards NR15 and NHO10.

For the species *E. grandis*, the highest level of vibration occurred with cutting set A, on the "x" axis, representing 91% of the acceleration. The vibration levels for cutting set A were 3% higher than for cutting set B, and both of them exceeded the action level established by NR15.

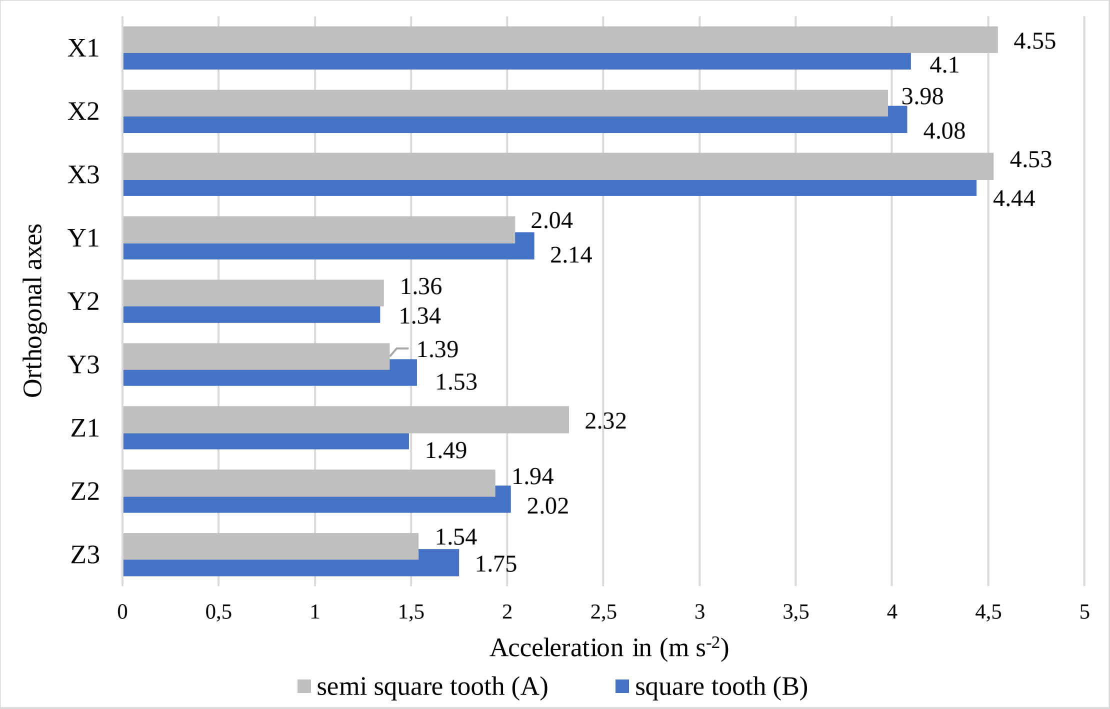

Figure 4. Hand-arm vibration acceleration values, for the two cutting sets, on the three orthogonal axes x, y and z in three forest species, *A. mearnsii*(1), *E. dunnii*(2) and *E. grandis*(3), respectively.
Figura 4. Aceleração média de vibração para mãos e braços, em dois conjuntos de corte nos três eixos ortogonais x, y e z em três espécies florestais, *A. mearnsii*, (1) *E. dunnii*, (2) e *E. grandis* (3), respectivamente.

After the statistical processing of the data, it was observed the non-normality of the data, which led to the use of the Kruskal-Wallis non-parametric test with multiple comparisons through the Bonferroni method. The acceleration values resulting from the orthogonal axes “x, y and z” for cutting sets A and B are described in Table 2.

Table 2. Average acceleration values for the different cutting sets and forest species evaluated.
Tabela 2. Valores de aceleração média para os diferentes conjuntos de corte e espécies florestais avaliadas.

		CCA	**CCB**
Species	**Axis**	**Average**	**Average**
Acácia mearnsii	X	17,2 a	15,9 a
Eucalyptus grandis		17,65 a	17 a
Eucalyptus dunnii		11,65 a	13,6 a
Acácia mearnsii	Y	23,1 a	20,7 a
Eucalyptus grandis		12,1 b	16 ab
Eucalyptus dunnii		11,3 b	9,8 b
Acácia mearnsii	Z	21,2 a	18,8 a
Eucalyptus grandis		9,6 b	13,2 a
Eucalyptus dunnii		15,7 ab	14,5 a

References: CSA = cutting set A; CSB = cutting set B. Means followed by the same letter in the column do not differ from each other by the Kruskal-Wallis test ($p<0.05$).

When comparing the interaction of the obtained results regarding the intensity of vibration for cutting sets A and B, the experiment pointed out that in the orthogonal axis “x”, the cutting set factor did not influence on the vibration produced by the chainsaw when performing the transversal cuts in the three forest species. For the orthogonal axis “x”, the species *E. grandis,* for one of the cutting sets, presented average values higher than that of *A. mearnsii*.

Regarding the “y” axis, it is highlighted the significant difference between all the species evaluated and for both cutting sets. This showed that the cutting set factor influenced on the sectioning of the wooden discs. When evaluating the “z” axis, a significant difference was observed between the vibration produced when performing the cross-sectional cut between species *A. mearnsii* and *E. grandis.*

DISCUSSION

The vibration magnitude of the chainsaw was dependent on the direction of the biodynamic axes (x, y and z), on the location/positioning of the transducers for measuring the vibration (right and left hand handles), on the condition of the chain and tooth sharpening, and not least, on the manner in which the machine was operated. The high result of acceleration for the species A. mearnsii, for cutting set A on the “x” axis, may be explained by the direction that the cutting set was positioned, in this case downwards, the same direction that the operator performed the cutting of the discs.

From the results, it is highlighted the use of new chains with teeth sharpened by the manufacturer, according to the standards. This same condition was used in the study developed by Rottensteiner and Stampfer (2013), in which they found a lower level of vibration exposure, mentioning that new chains and sharp teeth present 7.5% less transmissibility in relation to chain teeth with undesired sharpening conditions.

The average acceleration resulting from the normalized exposure to hand-arm vibrations showed significant differences in the values of the axes “y” and “z”. This was also evidenced by Kovác *et al.* (2018) when evaluating the effects of vibration and noise on operators of professional chainsaws. In addition, it should be noted that the dominant directions of the vibrations on the rear handle of the chainsaw were directions “y” and “z”, and it was also observed the influence of the type of cutting tooth and its wear on the registered vibration level.

Regarding the vibration data on axes “x, y and z”, the highest acceleration values were observed on the “x” axis, for the right hand. Corroborating, Goglia *et al.* (2006) and Dewangan *et al.* (2005) obtained similar results as those from this study, reinforcing that the highest levels of vibration transmission occurred on the “x” axis. Rukat *et al*. (2020), in their experiment, stated that the vibrations recorded when operating gasoline-powered chainsaws, at full load, are greater than when working at full speed without load. The authors also highlight that the acceleration of vibrations on the chainsaw handles depends on the direction of the wood cut (longitudinal and transversal).

From the point of view of the international regulation - Directive 2002/44/EC, the use of chainsaws may cause permanent damage to our health. In addition, Sell (2002) and Vendrame (2016) describe that operators exposed to high levels of vibration tend to develop the white finger syndrome, resulting in serious problems that must be taken into account to guarantee the physical integrity of the operator throughout his operational life.

In order to protect the operator's health, as well as to reduce the impact of the operation with chainsaws on the operator's life, Rottensteiner and Stampfer (2013) and Rukat *et al*. (2020) highlight the use of AV type gloves (anti-vibration) as an alternative to attenuate the vibration, which reaches the human being through his hands, which may be able to minimize the health risk caused by this physical agent. Corroborating the above, Grzywiński *et al.* (2016) state that the lack of personal protective equipment, suitable for these operations, may lead to negative effects on the operator’s health.

CONCLUSIONS

- The vibration levels to which the chainsaw operator was subjected, considering the conditions in which the work was carried out, exceeded the limits recommended by the Legislation, requiring the adoption of measures with the objective of reducing this exposure, through the use of appropriate PPE and shorter working hours.
- It is recommended the development of new design concepts for chainsaws, cutting sets and alternative materials by the industry, in order to minimize the levels of hand-arm vibrations, especially those related to the “x” axis, this way reducing the physical risks to operators when subjected to longer exposure time periods.

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