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Difference in the magnitude of power saw vibrations affecting the operator during forest felling

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Abstract

This study deals with a question whether the magnitude of vibrations affecting the power saw operator during the tree felling is still the same or not. For this purpose, the tree felling was broken down into several partial operations (pruning of lower tree part; cutting of buttresses; felling; delimbing) at which the values of vibrations were recorded and mutually compared. The vibrations were measured during the felling of 121 trees with the activity being made by one feller with one type of power saw and one type of power saw chain, and the felled trees included both live and dead standing trees. The vibrations were measured on the front and rear handles of the power saw in compliance with standards EN ISO 22867, EN ISO 5349-1 and EN ISO 5349–2. As to the mutual comparison, research results demonstrated a difference in 69.23% of cases. A maximum increase of vibrations during the experiment (17.0 m s^{-2}) was recorded on the rear handle during the partial activity of Delimbing live trees, the lowest increase of vibrations (0.320 m s^{-2}) being localized in the same partial activity, only on the front handle.

Key words: safety and health protection; stem wood moisture; forestry; work hygiene; dead standing tree; delimbing

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1. Introduction

Forest operations have always been prone to accidents, which places forestry workers among occupational groups facing higher risk of work accidents and occupational diseases than in many other sectors (Slappendel et al. 1993; osha.europa.eu). Working in the forest also represents substantial stress and is considered one of the most dangerous industrial activities (Gallis 2006; Yovi & Yamada 2019). In spite of technological and ergonomic improvements in forestry, some risk factors are still relatively high in forest workers and even some new risks have emerged (Marenče et al. 2017; Poje et al. 2019). Some forest operations such as motor-manual felling of trees remain permanently dangerous (Tsioras et al. 2014) even if high standards of safety and health protection in forestry are taken into account.

Many industrial sectors still rely upon motorized hand tools or manual work either due to low technology level or unavailable modern technologies in underdeveloped countries (Landekić 2019). Apart from real accidental risks, the long-term operation of motorized hand tools, namely power saws, is a main problem of occupational safety and health protection due to ergonomic load and physical fatigue (Potočnik & Poje 2017). The chain power saw is a working machine and has to be regularly checked and maintained to keep its performance and the safety of operators at the best. Operators should not start a working day without checking some key points of the power saw such as handles, throttle control, chain sharpness, chain tension, lubrication system, chain brake, guide bar wear etc.

Chain saws are still machines that are most frequently used in cleaning, felling and processing of trees in many regions of the world, and they are used also in several other industrial sectors (Albizu-Urionabarrenetxea et al. 2013), e.g. in gardening, building industry or arboriculture.

Using a power saw is connected with a range of adverse effects on the operator (Staněk et al. 2022), which may lead to occupational diseases and accidents both in the professional and non-professional field of work (Laschi et al. 2016). In forestry, power saw operators are

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exposed to occupational risks. In general, accidents with power saws are serious (Gallis 2006) and working conditions are difficult due to the presence of numerous occupational risks. Power saw operators are directly exposed to the working environment that may cause discomfort by weather and vegetation but also fatigue from moving in difficult terrains and associated risks such as tripping, slipping and injuries due to fall (Tsioras et al. 2014). The repeated or permanent exposure of power saw operators to unfavourable environmental conditions brings a risk of several types of occupational diseases and severe injuries including fatalities (Tsioras et al. 2014; Laschi et al. 2016). In addition, the operators are jeopardized by physical factors representing a health risk for them – noise, vibrations transmitted onto hands and arms (HAV hand-arm vibrations), exhaust gases and wood dust (Rottensteiner & Stampfer 2013; Magnusson & Nilsson 2011; Neri et al. 2016; Marchi et al. 2017; Kirisits et al. 2018; Poje & Potočnik 2018; Dimou et al. 2019).

Motors and cutting components of chain saws cause to their operators an oscillation movement commonly known as vibrations (Bačić et al. 2023). The transmission of vibrations onto the operator by means of handles is then associated with various vascular, neurological and musculo-skeletal disorders collectively called "hand–arm vibration syndrome" (Griffin 2004), namely vasoneurosis, Raynaud's syndrome and the syndrome of carpal tunnel (Neruda & Černý 2006). Power saw operators also have to face physical, physiological and environmental factors causing various diseases and particularly affecting muscles, skeleton, nerves, vascular system and hearing (Fonseca et al. 2015). Exposure of power saw operators to excessive physical load is also a risk factor significant in the onset of professional osteomuscular diseases (Iftime et al. 2022). Moreover, vibrations also affect internal body organs, back, ribs and jaw. If the vibrations reach a critical frequency, the body organs become oscillating, which may considerably harm a person's health (Rónay & Sláma 1989). Symptoms and diseases associated with the use of power saws in forests were characterized in many studies (Fonseca et al. 2015; Hooper et al. 2017). However, some of these risk factors such as vibrations and noise are underestimated by power saw operators as they do not represent immediate risks to human health (Neri et al. 2018).

Occupational risks induced by vibrations are further increased by binding forces connected with the type of saw, wood properties, individual biophysical characteristics and work technique of the operator (Malinowska-Borowska & Zieliński 2013). Neruda et al. (2015) inform that the impact of vibrations on the power saw operator increases in the cold and wet environment when hands become cold, blood flow in hands and fingers becomes insufficient, thus increasing the risk of illness.

What is the magnitude of vibrations affecting the power saw operator on the front and rear handle during individual partial activities and whether the values of vibrations induced during these individual partial activities differ remains however an unsolved question. There is also a question whether the magnitude of vibrations can be affected by the moisture content of wood of the felled tree (live × dead standing tree). Our research may provide answers to these questions.

2. Material and methods

2.1. Basic measurements

The research was conducted in the territory of the Czech Republic at the forest company of Lesy města Brna, a. s., forest district of Deblín. For the purposes of research, vibrations were measured during the felling 121 trees of Norway spruce (*Picea abies* (L.) H. Karst.).

Prior to the felling, each tree was measured for the moisture content of its wood using the instrument Greisinger Model GMH 3810. The measurement of wood moisture content proceeded as follows: a circle was drawn along the stem girth at a height of 130 cm from the ground. Four points were chosen on the circle, each corresponding to one of the four cardinal directions, in which the moisture content was measured. The measured moisture content values which were recorded with an accuracy of one tenth of a pecent were used to calculate an average for the whole stem. Then the trees were divided into two groups. Group 1 (Wet) included trees with a stem moisture content ranging from 50 to 100%. Group 2 (Dry) contained individuals with a stem moisture content below 50%. Both groups were subjected to the measurement of vibrations.

2.2. Power saw

All trees were felled by one power saw operator aged 59 years with 35 years of professional experience using at all times the same professional power saw (Stihl MS 362) with a power output of 3.5 kW, which was equipped with a 2-MIX engine (Table 1). According to the manufacturer,

Table 1. Basic parameters of Stihl MS 362 claimed by the manufacturer (Stihl 2022).

Technical specifications	Value
Displacement	59 cm^3
Power output	3.5/4.8 kW/bhp
Weight[1]	5.6 kg
Power-to-weight ratio	1.6 kg/kW
Sound pressure level[2]	106 dB(A)
STIHL Oilomatic saw chain type	Rapid Super (RS)
Sound power level[3]	117 dB(A)
Vibration level left/right[4]	3.5/3.5 $m\ s^{-2}$
Saw chain pitch	3/8"

[1]Without fuel, without bar and chain
[2]K-factor according to DIR 2006/42/EC = 2.5 (dB (A))
[3]K-factor according to DIR 2006/42/EC = 2.5 dB (A)
[4]K-factor according to DIR 2006/42/EC = 2 $m\ s^{-2}$

the saw has a very efficient anti-vibration system and an air filter system of very long service life. The cutting length of the bar of this power saw is 40 cm [Source: Stihl].

The type of saw chain used throughout the felling was one and the same (STIHL 3/8″ Rapid Super (RS), 1.6 mm, 40 cm with 60 links. The saw chain was sharpened by the power saw operator before the felling of each tree.

2.3. Measurement of vibrations

The magnitude of vibrations was measured and recorded by two accelerators Datalogger CEM model DT-178 A that were placed in a holder. The instruments feature an acceleration range of ±18 m s^{-2} and an acceleration resolution of 0.006 m s^{-2}. This model of the instrument was recording the magnitude of vibrations in three basic axes (x, y, z) and total shock in g (m s^{-2}). All records were provided an information about the time of measurement (CEM 2022). The time collection range was adjusted to 1 second. Records were stored in the internal memory of the instrument, which allows up to 85,500 data records (CEM 2022). Then, the data were exported into the PC using USB 2.0 and evaluated in the Vibration Datalogger 1.0 programme.

The magnitude of vibrations on the power saw handles was measured in compliance with standards EN ISO 22867, EN ISO 5349-1 and EN ISO 5349–2 (EN ISO 22867; EN ISO 5349-1; EN ISO 5349–2).

Pursuant to ISO 22867, specific measuring points and directions are established to declare emissions of vibrations (Fig. 1) (EN ISO 22867) on which the accelerometers were fixed (EN ISO 5349–2). On the front handle, the accelerometer was placed 25 mm ±3 mm to the left from the guide bar plane, and on the rear handle, the accelerometer was placed 20 mm ±3 mm in front of the throttle trigger rear, precisely as stipulated by standard EN ISO 22867 (EN ISO 22867).

Vibrations and their magnitudes were measured during the common work of the power saw operator, in line with EN ISO 5349–2 stipulating that the measurement

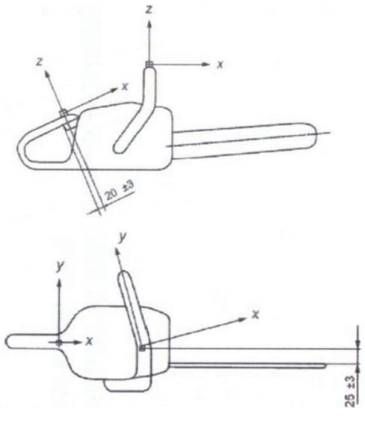


Fig. 1. Major steps and activities regarding implementation of the transnational non-native tree strategy.

represents average for an interval which is representative for the typical use of mechanized tools, machines or work procedures (EN ISO 5349–2) (power saw in our case). The interval of measurement should start at the moment when the operator's hands get first into contact with the vibrating surface, and end when the contact is discontinued (EN ISO 5349–2). The same standard stipulates that a number of indicative measurements should be taken during the day at diverse times, which should be averaged to capture variations during the day.

Based on the data, effective values of frequency weighted vibrations transmitted onto hands in the individual directions (a_{hw}) were calculated in m s^{-2} according to the following formula:

$$a_{hw} = \sqrt{\frac{1}{T}\sum_{1}^{N} a_{hwj}^{2} t_j}$$

where:

a_{hwj} magnitude of vibrations measured in the j^{th} direction;

t_j time of measuring the j^{th} direction;

$$T = \sum_{1}^{N} t_j$$

2.4. Partial activities

In order to achieve the research goal, the manufacturing process was broken down into four partial operations: pruning of the lower tree part; cutting off buttresses; felling; delimbing. It should be added that the evaluation of the magnitude of vibrations affecting the power saw operator in the below described partial activities included also the non-productive time, i.e. the time when the engine of power saw held by one hand (or both hands) of the operator was on but not used for cutting or any other activity. This specifically applied to walking around of the operator, to moving the power saw between individual branches that were cut off etc. The characterization of individual partial activities follows:

Cleaning – This partial activity started with the pruning of branches on the lower part of the standing tree before its felling. The branches were removed on all sides of the tree up to ca. 150 cm from the tree foot. The partial activity ended with the removal of the last branch occurring in the mentioned space of the standing tree. This partial activity has been only on live trees. The dry trees had no branches in this part of the tree.

Butt – This partial activity started with cutting off buttresses on the standing tree and ended at the moment when the power saw operators cut off the last buttress.

Felling – This partial activity started at the moment when the cutting into the tree trunk started with an aim to create a directional notch at the tree foot. It included the creation of the notch and the back cut for the purpose of tree felling. The end of this partial activity was considered to

be a moment when the power saw operator stopped in making the back cut, retreated, and the tree began to fall to the ground spontaneously.

Delimbing – This was a partial activity during which the already felled tree was delimbed, the trunk was cross-cut into logs and the tree top was removed. It started with the delimbing (cut into the first branch) and ended at the moment when the power saw operator has had cut off the tree top.

For a better orientation in the results, the individual operations were allocated the following abbreviations:

FH Wet – front handle, live trees with wet wood (Group 1 of trees);

RH Wet – rear handle, live trees with wet wood (Group 1 of trees);

FH Dry – front handle, dry trees (Group 2 of trees);

RH Dry – rear handle, dry trees (Group 2 of trees).

Video records taken during the process of tree felling allowed to allocate the measurement data to the respective activities. The records served to delimit the respective work operations and to allocate the measured vibration magnitudes to them. The video was taken using the action camera VegaX Pro (Niceboy) which was at all times focusing the felled tree during the entire time of its processing.

2.5 Statistical analyses

Data recorded by vibrometers during the manufacturing process of motor-manual felling were broken down by the respective partial activities and mutually compared, specifically individual data files of vibrations from the front and rear handles of the power saw as well as results from the measurements of vibrations during the partial activities at felling dry and live (wet) trees.

For this purpose, the data were analysed in the STATISTICA 14 software (TIBCO) and subjected to the Shapiro-Wilk test of normality for the correct evaluation. In the test, the size of p-value was set to 0.05, which means that if a situation occurred when the test result exceeded the value, then the data corresponded to the Student division, and the following test was one-factor ANOVA, again with the p-value of 0.05. Then the vibrations from the respective operations differed from each other when the result of the statistical test exceeded the set up value. If the Shapiro-Wilk test result was lower than the p-value set up therein, then the data corresponded no more to the mentioned division. In such case, a non-parametric test was used (the Kruskal-Wallis test whose p-value was again set up to 0.05). The partial activities and their data differed from each other if the test result exceeded the p-value. Descriptive statistics for the respective activities and their data, and a box plot were to better illustrate the data. Data obtained from the measurement of stem wood moisture content were processed in the STATISTICA 14 software (TIBCO), being subjected to the descriptive statistics only.

3. Results

As to the moisture content measurement, 73 of 121 trees were classified as Wet. A tree with the lowest moisture content in this group reached 83.5% and a tree with the highest moisture content reached 99.8%. The mean moisture content of trunk wood in this group of trees was 93.5%. The Dry group included the remaining 48 trees of which an individual with the lowest moisture content reached only 11.8% and an individual with the highest moisture content (in this group) reached 29.3%. The mean moisture content of trunk wood in this group of trees was 20.0%. Fig. 2 shows the distribution of recorded vibrations affecting the operator of manual power saw during individual partial activities of motor-manual felling of live (wet) and dry timber. The densest concentration of vibrations was recorded on the rear handle (RH) during the partial operation of Cleaning live timber (from 1.210 to 9.140 m s^{-2}). This maximum value can be considered the lowest maximum measured during the respective partial activities. Thus, the highest recorded maximum was 17.000 m s^{-2}, which is by 7.860 m s^{-2} more. An absolute maximum of vibrations was recorded on the rear handle during the partial operation of Delimbing live tree. However, also the lowest vibration of all measurements (0.320 m s^{-2}) during this partial activity was recorded on the FH armrest. The highest value of minimum vibrations during the respective partial activities was 2.010 m s^{-2} which was reached in several partial activities (Felling FH Dry, Felling RH Dry and Butt RH Dry. A considerable difference can also be seen in Fig. 2 in the partial activity of Delimbing RH Dry between the median (3.470 m s^{-2}) and the mean value (4.110 m s^{-2}). The difference between these magnitudes of vibrations in behalf of mean vibration points to a greater concentration of high value reaching extremes. The claim is also supported by the high value of standard deviation (2.226 m s^{-2}).

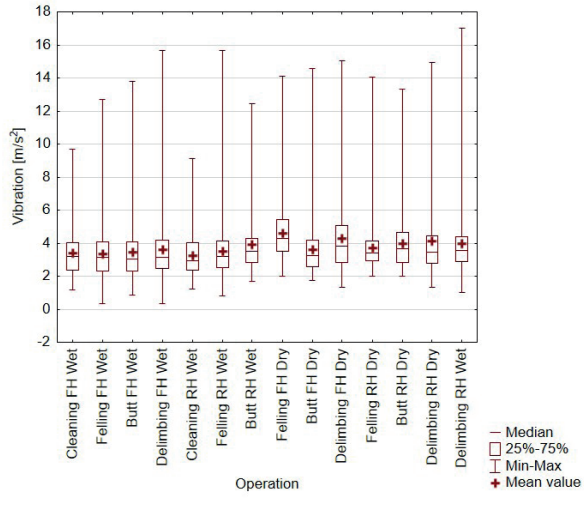


Fig. 2. Distribution of vibrations during the respective partial activities.

Table 2 shows statistic results of the mutual comparison of individual partial activities as mentioned in the section of Statistic analyses. Values of individual statistic tests demonstrate the difference of compared partial activities nearly in all cases. There were several exceptions in the results though. The first of them was the comparison of Cleaning FH Wet partial activity with the following partial activities: Felling FH Wet, Butt FH Wet, Delimbing FH Wet, Felling RH Wet. Compared with the partial activity of Felling FH Wet, a difference between mean vibrations affecting the power saw operator was only 0.031 m s^{-2} in behalf of the first mentioned partial activity.

When comparing the Cleaning FH Wet and the Butt FH Wet partial activities, the difference between the magnitudes of mean vibrations was somewhat greater than in the previous comparison but it was still rather low. Specifically, it was only 0.036 m s^{-2} in behalf of the Butt FH Wet partial activity whose mean vibration reached 3.441 m s^{-2}. The statistic analysis also dismissed a possibility of different values of vibrations when comparing the partial activities of Cleaning FH Wet and Delimbing FH Wet, in spite of the fact that a maximum value of vibrations in Cleaning FH Wet amounted to 9.670 m s^{-2}, which was by 6.000 m s^{-2} less than in Delimbing FH Wet. The difference between mean vibrations during these partial activities was rather low, only 0.187 m s^{-2}. The same result about the dismissal of differences between the vibrations was reached also when comparing the front and rear handles during Delimbing live trees. Mean vibrations on the front and rear handles were 3.405 m s^{-2} and only 3.247 m s^{-2} respectively (see Table 3) and a difference between them amounted to 0.158 m s^{-2}. An even lower value of difference was recorded in the minimum values of vibrations, only 0.050 m s^{-2}. It was further statistically demonstrated that the magnitude of vibrations affecting the power saw operator during the partial activities of Cleaning FH Wet and Felling RH Wet was identical, which was also corroborated by the difference between the mean vibrations, which was 0.081 m s^{-2}. During the partial activity of Cleaning FH Wet, the power saw operator was most frequently affected by vibrations reaching 2.410 m s^{-2}, which was by 0.140 m s^{-2} less than in Felling RH Wet. The last partial activity whose values of vibrations were identical with Cleaning FH Wet was But FH Dry during which the power saw operator was affected by vibrations reaching 2.230 m s^{-2}, which was by 0.180 m s^{-2} less than in Cleaning FH Wet.

Another exception in the results presented in Table 2 is the comparison of Felling FH Wet with the following partial activities: Butt FH Wet and Cleaning RH Wet. The comparison of Felling FH Wet and Butt FH Wet revealed a difference between the mean magnitude of vibration amounting only to 0.067 m s^{-2}. A greater difference was reached when Felling FH Wet and Cleaning RH Wet were compared (0.127 m s^{-2}, which was less than the difference of 0.880 m s^{-2} recorded in minimum vibrations. No difference in data was demonstrated when Butt FH Wet was compared with the partial activities of Delimbing FH Wet, Cleaning RH Wet, Felling RH Wet and Butt RH Dry. A mean Butt FH Wet vibrations reached 3.441 m s^{-2} and the Delimbing FH Wet vibrations were greater by 0.151 m s^{-2}, thus amounting to 3.592 m s^{-2} (see Table 3). A similar deviation (0.194 m s^{-2}) was recorded when mean vibrations were compared with Cleaning RH

Table 2. Results of the statistic comparison of the individual partial activities.

Operation	Cleaning FH Wet	Felling FH Wet	Butt FH Wet	Delimbing FH Wet	Cleaning RH Wet	Felling RH Wet	Butt RH Wet
Cleaning FH Wet	—	1.000	1.000	1.000	1.000	1.000	<0.050
Felling FH Wet	1.000	—	1.000	<0.050	1.000	<0.050	<0.050
Butt FH Wet	1.000	1.000	—	1.000	1.000	1.000	<0.050
Delimbing FH Wet	1.000	<0.050	1.000	—	<0.050	1.000	<0.050
Cleaning RH Wet	1.000	1.000	1.000	<0.050	—	<0.050	<0.050
Felling RH Wet	1.000	<0.050	1.000	1.000	<0.050	—	<0.050
Butt RH Wet	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	—
Delimbing RH Wet	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	1.000
Felling FH Dry	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Butt FH Dry	1.000	<0.050	0.066	1.000	<0.050	1.000	1.000
Delimbing FH Dry	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Felling RH Dry	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	1.000
Butt RH Dry	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	1.000
Delimbing RH Dry	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	1.000

Operation	Delimbing RH Wet	Felling FH Dry	Butt FH Dry	Delimbing FH Dry	Felling RH Dry	Butt RH Dry	Delimbing RH Dry
Cleaning FH Wet	<0.050	<0.050	1.000	<0.050	<0.050	<0.050	<0.050
Felling FH Wet	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Butt FH Wet	<0.050	<0.050	0.066	<0.050	<0.050	<0.050	<0.050
Delimbing FH Wet	<0.050	<0.050	1.000	<0.050	<0.050	<0.050	<0.050
Cleaning RH Wet	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Felling RH Wet	<0.050	<0.050	1.000	<0.050	<0.050	<0.050	<0.050
Butt RH Wet	1.000	<0.050	1.000	<0.050	1.000	1.000	1.000
Delimbing RH Wet	—	<0.050	<0.050	<0.050	0.144	1.000	1.000
Felling FH Dry	<0.050	—	<0.050	<0.050	<0.050	<0.050	<0.050
Butt FH Dry	<0.050	<0.050	—	<0.050	0.695	<0.050	<0.050
Delimbing FH Dry	<0.050	<0.050	<0.050	—	<0.050	1.000	<0.050
Felling RH Dry	0.144	<0.050	0.695	<0.050	—	0.370	1.000
Butt RH Dry	1.000	<0.050	<0.050	1.000	0.370	—	1.000
Delimbing RH Dry	1.000	<0.050	<0.050	<0.050	1.000	1.000	—

< 0.050 = operations difference (red)

Table 3. Descriptive statistics.

Operation	Mean Value [m s^{-2}]	Median [m s^{-2}]	Mode [m s^{-2}]	Frequency of Mode	Min. [m s^{-2}]	Max. [m s^{-2}]	Standard Deviation [m s^{-2}]
Cleaning FH Wet	3.405	3.200	2.410	11	1.160	9.670	1.289
Felling FH Wet	3.374	3.130	2.250	25	0.330	12.680	1.470
Butt FH Wet	3.441	3.030	Multiple	9	0.840	13.770	1.702
Delimbing FH Wet	3.592	3.170	2.610	92	0.320	15.670	1.828
Cleaning RH Wet	3.247	2.950	2.960	10	1.210	9.140	1.190
Felling RH Wet	3.487	3.190	2.550	34	0.800	15.650	1.417
Butt RH Wet	3.934	3.495	2.410	9	1.710	12.460	1.807
Delimbing RH Wet	3.982	3.540	2.910	110	1.030	17.000	1.893
Felling FH Dry	4.616	4.310	3.610	28	2.010	14.110	1.634
Butt FH Dry	3.628	3.250	2.230	16	1.740	14.550	1.468
Delimbing FH Dry	4.309	3.840	2.110	43	1.310	15.050	2.054
Felling RH Dry	3.728	3.415	2.840	40	2.010	14.030	1.373
Butt RH Dry	3.957	3.660	Multiple	10	2.010	13.310	1.520
Delimbing RH Dry	4.110	3.470	2.910	68	1.330	14.940	2.226

Wet. However, maxima reached in the respective partial activities differed from each other (difference of 4.630 m s^{-2}). In spite of results of the statistic test reaching values higher than the set up p-value, the results were evaluated as undifferentiated. Data identical according to the statistic analysis with Butt FH Wet were contained also in Felling RH Wet. These partial activities and their mean vibrations differed from each other by 0.046 m s^{-2} to the disadvantage of Felling RH Wet (3.487 m s^{-2}). The last partial activity identical in terms of vibrations with Butt FH Wet was Butt RH Dry. The comparison showed that maximum vibrations recorded in the respective partial activities differed from other only by 0.780 m s^{-2}. Similar values were recorded also in the minimum which was 0.900 m s^{-2}. The lowest difference in the minimum and maximum values of identical data was however recorded when comparing Delimbing FH Wet and Felling RH Wet, the difference being 0.020 m s^{-2} for the maximum and 0.480 m s^{-2} for the minimum.

The comparison of Delimbing FH Wet and Butt FH Dry, which did not differ according to results in Table 2, revealed a difference of 0.036 m s^{-2} in the mean vibrations, with a mean magnitude of vibrations in the partial activity of Butt FH Dry reaching 3.628 m s^{-2}. The partial activity of Butt FH Dry and its data were evaluated as undifferentiated when compared with Felling RH Wet, which is also indicated by the difference between the mean values, which amounted to 0.141 m s^{-2}. The result about the data invariance was arrived at when comparing Butt RH Wet with the following partial activities: Butt FH Dry, Felling RH Dry, Butt RH Dry and Delimbing RH Dry. A mean difference between the partial activities of Butt RH Wet and Butt FH Dry was 0.306 m s^{-2} in spite of the fact that maxima reached in Butt RH Wet and Butt FH Dry were 12.460 m s^{-2} and 14.550 m s^{-2} respectively. A similar maximum was reached in Felling RH Dry (14.030 m s^{-2}), which was by 1.570 m s^{-2} more than when compared with Butt RH Dry. Despite the fact, the partial activities were also evaluated as undifferentiated, too. During the partial activity of Butt RH Dry, the same vibrations were recorded as in Delimbing RH Dry. Data difference was hardly observed, which was corroborated also by the difference between the mean vibration magnitude (0.177 m s^{-2}). The same result was also recorded in the comparison with the partial activity of Felling RH Dry in which the vibration most frequently reached 2.840 m s^{-2}, which is nearly the same value as recorded in Delimbing RH Dry (2.910 m s^{-2}). Other undifferentiated partial activities in terms of the magnitude of vibrations included the comparison of Butt FH Dry and Felling RH Dry, where a difference between the mean value of vibration was 0.100 m s^{-2} or the comparison between Delimbing FH Dry and Butt RH Dry. A difference in the mean values was 0.353 m s^{-2}. The first from the last three undifferentiated pairs of partial activities compared using the statistic analysis was Felling RH Dry and Butt RH Dry. In this case, a difference between the mean value of vibrations was 0.229 m s^{-2}. The second pair was consisting of partial activities Felling RH Dry and Delimbing RH Dry, whose difference amounted to 0.383 with the Modus being nearly identical (2.840 m s^{-2} and 2.910 m s^{-2}, resp) (see Table 3). The last pair of partial activities whose values of vibrations did not differ included Butt RH Dry and Delimbing RH Dry. Looking closer at Table 3, a difference between the mean magnitude of vibrations was only 0.154 m s^{-2}.

In general, Table 2 shows a great number of combinations in the comparison; in 30.77% of cases, a difference of vibrations was not demonstrated. This indicates that vibrations in the respective partial activities during the motor-manual felling, be them affecting the front or rear handles or be them produced during the felling of live or dry trees, differed in 69.23% of cases.

4. Discussion

The issue of measuring vibrations is a very specific topic at which many variable factors have to be taken into account. For this reason, a comparison of results from other research studies would not be relevant; they can be compared only in terms of their ratios.

Pursuant to Directive no. 2006/42/EC (European Parliament 2006), manufacturers are obliged to provide the following data about vibrations transmitted by manual or manually controlled machines: total value of vibrations to which the hands are exposed if they exceed

2.5 m s^{-2} and measurement uncertainty. According to the official Stihl MS 362 Instructions for use (Stihl 2022), values of vibrations represent 3.5 m s^{-2} for the left handle and 3.5 m s^{-2} for the right handle.

The results of our research show that the value of vibrations in all compared partial activities was at all times higher in the felling of dry trees. The fact might have been given by the finding of Rottensteiner et al. (2012) that wood density affects the magnitude of vibrations transmitted onto the hand during cutting operations with the power saw, the fact being caused by physical and mechanical properties of wood. Soft wood absorbs vibrations better than hard wood (Kováč et al. 2018).

Rottensteiner et al. (2012) conducted their research on power saws of the same performance class as that of Stihl MS 362 and found out that the weighted means of vibrations with no regard to tree species were 5.54 m s^{-2} for Husqvarna 357 XP and 4.26 m s^{-2} for Husqvarna 372 XP. In another research study conducted by Malinowska-Borowska et al. (2012), vibrations on the front chain saw handle and the sum of accelerations in three axes ranged between 5.4 and 5.9 m s^{-2}. The results of both studies brought higher values than those recorded in our research. Results of research conducted by Landekić et al. (2020) showed that the groups of power saws (Stihl MS 260 and Stihl MS 440) featured the highest values of vibrations most often on the front handle while the Stihl MS 660 power saws exhibited the highest values of vibrations measured on the rear handle. Another study on Stihl MS 230 (Feyzi 24) concluded that the highest values of vibrations occurred on the rear handle when idling.

According to Goglia et al. (2012), the HAV (hand-arm vibrations) load was exceeding the action value of daily exposures during the work with the power saw in the thinned stands. In order to reduce the exposure to HAV, Rottensteiner & Stampfer (2013) tried using a Kasper safety bar on the power saw, finding out however that the exposure to HAV did not change with the use of this bar as compared with the use of the conventional bar. Rottensteiner et al. (2012) add that HAV differs in the tree species and is higher in those with a higher wood density. One of possible measures to reduce the harmful impact of HAV on power saw operators is the use of anti-vibration gloves which have to comply to international standards (Goglia et al. 2008).

Grip strength of power saw handle affecting the transmission of HAV depends on the operator's experience, work procedures and wood hardness. This means that forces developed by power saw operators are higher in less experienced workers, greater in felling and cross-cutting than in delimbing, and greater in tree species of higher wood hardness (Malinowska-Borowska et al. 2012; Malinowska-Borowska & Zieliński 2013; Yovi & Yamada 2019). According some other research works Goglia et al. 2012; Yovi & Yamada 2019), the level of power saw vibrations is also affected by the chain tension, bar length, fuel amount in the tank and the way of holding the saw.

When studying the impact of vibrations on human organism, it is also necessary to take into account the power saw type used as well as partial activities. The research made by Poje et al. (2018) indicates that the exposure to HAV is lower (by on average 1.23 m s^{-2}) when using the electric power saw as compared with the petrol chain saw. The fact that electric power saws transmit lower magnitudes of vibrations onto the operators has been confirmed also by other authors (Neitzel & Yost 2002). It is no less important to keep pointing out the type of correct chain saw sharpening as Marenče et al. (2017) concluded that the angle of chain sharpening affects the hand-arm vibrations, too.

The magnitude of vibrations transmitted onto saw operators can be also affected by using different fuel mixtures. Rak (2018) measured vibrations on the same power saw that was used by us in our research. He used different mixtures of petrol (Shell V-Power Racing 100 and BA 95 Natura) and oil (M2T and HP Ultra). Results of his research are as follows. When combining different petrol and oil mixtures, mean values of vibrations recorded in total acceleration [m s^{-2}] and idling power saw were 4.81 m s^{-2} (Shell V-Power Racing 100 and M2T); 4.80 m s^{-2} (Shell V-Power Racing 100 and HP Ultra); 5.41 m s^{-2} (BA 95 Natura and M2T); 5.14 m s^{-2} (BA 95 Natura and HP Ultra). He also recorded mean values of vibrations when combining different petrol and oil mixtures in total acceleration m s^{-2} with the power saw operation at a so-called "half throttle" with the following results: 12.78 m s^{-2} (BA 95 Natura and M2T); 13.13 m s^{-2} (BA 95 Natura and HP Ultra); 12.32 m s^{-2} (Shell V-Power Racing 100 and M2T); 11.61 m s^{-2} (Shell V-Power Racing 100 and HP Ultra).

National and international standards stipulate that employers have to adopt measures necessary for the safety and health protection of their employees including the prevention of occupational risks, which is a fundamental principle in the law of many countries (Yangho et al. 2016; Mohammadfam et al. 2017). For the prevention of injuries caused for example by power saws, considerable educational resources and aids are available (Occupational Safety and Health Administration 2007).

5. Conclusion

During the research, a great number of combinations was found in the comparison; a difference of vibrations was not demonstrated in 30.77% of cases. This indicates that vibrations in the respective partial activities during the motor-manual felling, be them acting on the front or rear handles or be them produced during the felling of dry or live trees, differed in 69.23% of cases. The greatest maxi-

mum of vibrations was recorded on the rear handle during Delimbing live trees. During this partial activity, also the lowest vibration of all measurements was recorded on the front handle, which was 0.320 m s^{-2}. The lowest difference in the minimum and maximum values of identical data was recorded when comparing live trees in the partial activities of Delimbing on the front handle and Felling on the rear handle. The highest value of minimum vibrations recorded in the individual partial activities was 2.010 m s^{-2}. This value was reached in the following several partial activities: Felling FH Dry, Felling RH Dry and Butt RH Dry. The densest concentration of vibrations was recorded on the rear handle during the partial activity of Cleaning live trees (from 1.210 to 9.140 m s^{-2}).

Results obtained from the research show that the highest mean of vibrations was recorded on the power saw front handle during the Felling of dry trees while the lowest mean of vibrations was recorded on the rear power saw handle during the Cleaning of live trees.

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