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Wood Density Impact on Hand-Arm Vibration

Christian Rottensteiner, Petros Tsioras, Karl Stampfer

Abstract – Nacrtak

Despite technological advancements in machinery for timber harvesting, chainsaws are frequently used in forest operations. In Austria 85% of the wood volume harvested (15 million m³) are cut by chainsaws. The two most frequently documented ergonomic threats during motor manual felling include exposure to noise and vibration. This paper presents the results of exposure to hand-arm vibration with focus on the impact of different density of wood species. Vibration exposure during crosscutting of Black poplar (oven-dry density of 400 kg/m³), Norway spruce (oven-dry density of 360 kg/m³) and European beech (oven-dry density of 700 kg/m³) was measured on three Husqvarna chainsaw models differing in size and power output. Measurement and analysis of vibration were carried out in accordance with guidelines of ISO 5349-1 and ISO 5349-2. The results show that total values of unweighted root mean square (rms) vibration acceleration do not differ between tree species. Anyway, frequency-response curve of beech differed from that of poplar and spruce. Applying the weighting filter of ISO 5349-1, the frequency-weighted vibration of beech had higher values than those of poplar and spruce. No significant differences were found between poplar and spruce. Vibration values (measured on chainsaw rear handle) ranged from 4.06 m/s² to 4.92 m/s² for poplar, 4.38 m/s² to 5.66 m/s² for spruce, and 5.84 m/s² to 7.38 m/s² for beech, respectively.

Keywords: chainsaw, hand-arm vibration, wood density, vibration, poplar, spruce, beech

1. Introduction – *Uvod*

Chainsaw represents a very important tool for forest operations. Despite technological advancements that resulted in a wide range of machinery specialized for wood harvesting, chainsaws are frequently used in forest operations. This is due to multiple reasons such as low level of mechanization (Sessions 2007; Tsioras 2010), difficulty in obtaining capital for investments in new machinery (Uusitalo and Markkola 2006), unwillingness to invest in small-scale forestry practices due to high operational costs (Blinn et al. 1986; Wang et al. 2004) or large diameters of timber (Wang et al. 2004). However, the predominant reason is the fact that in many cases, felling operations can only be done by means of chainsaws because the steepness of the terrain makes the trafficability by machinery impossible and hence also the use of more mechanized operations (Heinimann 1999; Hall and Han 2006; Hittenbeck 2007). In Austria 85% of the wood volume harvested (15 million m³) are cut by chainsaws (BMLFUW, 2011).

The use of chainsaws has been connected to a large number of ergonomic threats. Forest workers are affected by exhaust gas (Alander et al. 2005; Magnusson and Nilsson 2011), wood dust (Horvat et al. 2005; Puntaric et al. 2005; Kauppinen et al. 2006) and poor body posture causing lower back injuries (Hagen 1990; Hagen et al. 1998). However, the two most frequently documented threats during motor manual felling include exposure to noise and vibration.

Extensive research has been done with regard to the measurement of the vibration during working with chainsaw (Cristofolini et al. 1990; Neitzel and Yost 2002; Pitts 2004), the effect of technological developments on the mitigation of hand-arm vibration (HAV) (Starck 1984; Koskimies et al. 1992), the prevalence of vibration induced white finger (VWF) and vascular disorders (Hellstrom and Andersen 1972; Futatsuka and Ueno 1986; Bovenzi 2008; Bovenzi et al. 2008), and musculoskeletal disorders due to HAV (Bovenzi et al. 1991; Kaewboonchoo et al. 1998). However, no studies have examined so far the effect of wood density on the exposure to vibration during work with the chainsaw. The originality of this study lies in the investigation of wood density impact on HAV. Different wood species have different wood structure and this is expected to differentiate the results of vibration exposure.

Keeping these factors in consideration, the present study was undertaken in Lower Austria with the objective to increase our knowledge about the impact of different density of wood species on HAV. For this reason, HAV exposure during crosscutting operations was measured on poplar, spruce and beech.

2. Material and Methods – *Materijal i metode*

2.1 Study layout – Raspored istraživanja

The experiment was carried out for investigating a potential influence on the vibration magnitude arising from chainsaws cutting tree species of differing wood density (Fig. 1).

The data set was comprised of ten samples for each of the three species. This procedure was repeated for each one of the three chainsaw models used in the present study, resulting in a total of 90 measurement samples.

The tree species under study were Black poplar (*Populus nigra*), Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*). Oven-dry density was found to be 400 kg/m^3, 360 kg/m^3 and 700 kg/m^3, respectively. The oven-dry mass was determined on samples, according to the oven dry method (CEN/TS 14774-1:2004). The corresponding volume was achieved by dip-coating using Archimedes' principle, according to which the upward force of a body immersed in water is equal to the weight of the amount of water the body displaces. Considering the fact that the specific gravity of water is 10 N/dm^3 one can directly get the volume by reading the measurement result on a scale. Finally, oven-dry density for each sample was calculated by dividing the sample mass by its volume.

The saw-logs of the above mentioned species that were used in this study had a diameter that ranged from 30 to 43 cm at the middle of their length. They were placed on a sawbuck 50 cm above ground, so that the operator was able to cut slices of four centimeters, until the designated sample time of two minutes was reached. ISO standard 5349-2 (ISO 2001b) stipulates that at least three samples of minimum one minute duration should be taken. Vibration was measured on the front and rear handle simultaneously. Each saw was equipped with a chain originally sharpened by the manufacturer, in order to eliminate the possibility of higher vibration values due to blunt chain. One new chain was mounted on each chainsaw, and it was used for all measurement samples for the same tree species.

2.2 Characteristics of chainsaws and operator *Značajke motorne pile i sjekača*

Three brand-new Husqvarna chainsaws differing in size and power output were operated during all measurements (Table 1). The operator was a profes-

Husqvarna 346	Husqvarna 357 XP	Husqvarna 372 XP
		
Power = 2.7 kW *Snaga* = 2,7 kW	Power = 3.2 kW *Snaga* = 3,2 kW	Power = 3.9 kW *Snaga* = 3,9 kW
Black poplar (ρ = 400 kg/m^3) ***Crna topola*** (ρ = 400 kg/m^3)	**Black poplar** (ρ = 400 kg/m^3) ***Crna topola*** (ρ = 400 kg/m^3)	**Black poplar** (ρ = 400 kg/m^3) ***Crna topola*** (ρ = 400 kg/m^3)
Norway spruce (ρ = 360 kg/m^3) ***Obična smreka*** (ρ = 360 kg/m^3)	**Norway spruce** (ρ = 360 kg/m^3) ***Obična smreka*** (ρ = 360 kg/m^3)	**Norway spruce** (ρ = 360 kg/m^3) ***Obična smreka*** (ρ = 360 kg/m^3)
European beech (ρ = 700 kg/m^3) ***Obična bukva*** (ρ = 700 kg/m^3)	**European beech** (ρ = 700 kg/m^3) ***Obična bukva*** (ρ = 700 kg/m^3)	**European beech** (ρ = 700 kg/m^3) ***Obična bukva*** (ρ = 700 kg/m^3)

Fig. 1 Study layout
Slika 1. *Svojstva*

Table 1 Equipment characteristics
Tablica 1. *Mjerna oprema*

Chainsaw type *Vrsta motorne pile*	Weight, kg *Masa, kg*	Cylinder displacement, cm^3 *Obujam cilindra, cm^3*	Power output, kW *Izlazna snaga, kW*	Bar length, cm *Duljina vodilice, cm*	Cutting tooth profile *Oblik zubaca na lancu lanca*	Chain pitch, " *Korak lanca, "*	# drive links *Br. pogonskih članaka*	Gauge, mm *Mjera, mm*
346 XP	5.0	50.1	2.7	38	Semi-chisel	0.325	64	1.3
357 XP	5.5	56.5	3.2	45	Semi-chisel	0.325	72	1.3
372 XP	6.1	70.7	3.9	50	Semi-chisel	0.375	68	1.5

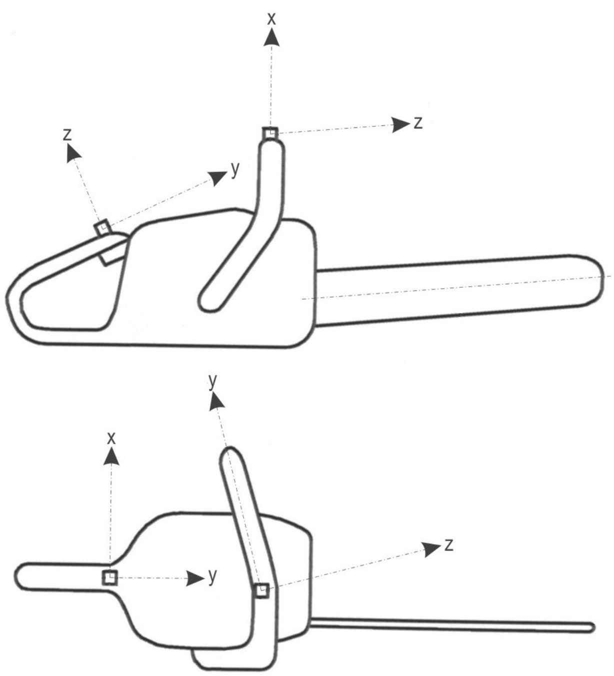

Fig. 2 Orientation of biodynamic axes
Slika 2 *Osi mjerenja vibracija*

sionally trained forest worker with experience in timber harvesting of eight years, who was requested to work at a normal work pace.

2.3 Vibration measurement – *Mjerenje vibracija*

Two Brüel&Kjaer cubic triaxial piezoelectric accelerometers of the type 4524-B were used for simultaneous vibration measurements in three perpendicular directions on the chainsaw front and rear handle (Fig. 2).

These transducers were fixed by a mounting clip stuck with ceramic adhesive glue. That ensures that there is no damping between the chainsaw and transducers and vibrations are correctly measured in accordance with ISO standard 5348 (ISO 1998). The accelerometer weight was 4.4 g. The orientation of the measurement axes and the accelerometer mount was done as described in the ISO standards 5349-1 (ISO 2001a) and 5349-2 (ISO 2001b).

A Brüel&Kjaer LAN-XI 6-channel input module of the type 3050 with a frequency range from 0 to 51.2 kHz and 160 dB dynamic range was used for data recording. This portable data logger was driven by an accumulator; data were stored on a SD (Secure Digital) memory card for post-processing.

Calibration was done before each measurement with the help of a Brüel&Kjaer calibration exciter of the type 4294, which produces an acceleration signal of 10 m/s² at a frequency of 159.2 Hz.

2.4 Data analysis – *Obrada podataka*

The collected vibration data were analyzed with the Brüel&Kjaer PULSE LabShop 14.1 software. More specifically, the root-mean-square (rms) acceleration, at one-third octave bands in the frequency range between 6.3 and 1250 Hz, was used for the calculation of the weighted rms accelerations for each axis (a_{hwx}, a_{hwy}, a_{hwz}). The weighting factors according to ISO standard 5349-1 (ISO 2001a) were applied. The total vibration value a_{hv} (1) was calculated from the frequency weighted acceleration of all three axes with the following equation:

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

Identification of potential differences between the examined factors (wood density, type of chainsaw) was conducted with the help of analysis of variance (ANOVA), which is included in the software package PASW Statistics 18. Post-hoc analysis for investigating potential differences between tree species and chainsaw type was done using Bonferroni's test. Significance level for all tests was set at 5%.

3. Results – *Rezultati*

3.1 Wood density impact on frequency-unweighted HAV – *Utjecaj gustoće drva na frekvencije nevrednovanih ubrzanja u sustavu šaka–ruka*

ANOVA and post-hoc analysis of frequency-unweighted vibration acceleration revealed no differences between the tree species (Table 2). As seen in Table 3, vibration values of chainsaws for the rear handle exceeded those for the front handle. Differences between handles were statistically significant. Values measured on Husqvarna 346 XP were on the same level with those of Husqvarna 372 XP, while on Husqvarna 357 XP higher vibration acceleration was found.

Table 2 Bonferroni's test for frequency-unweighted vibration
Tablica 2. *Bonferronijev test za frekvencije nevrednovanih ubrzanja*

Tree species, I *Vrsta stabala, I*	Tree species, J *Vrsta stabala, I*	Mean Difference, I–J *Glavna razlika, I–J*	Std. error *Standardna pogreska*	Sig. *Značajno*	95% Confidence Interval *95 % interval pouzdanosti*	
					Lower bound *Donja granica*	Upper bound *Gornja granica*
Poplar – *Topola*	Spruce – Smreka	0.3214	3.38344	1.000	–7.8640	8.5068
	Beech – Bukva	–0.3796	3.35667	1.000	–8.5003	7.7410
Spruce – *Smreka*	Poplar – Topola	–0.3214	3.38344	1.000	–8.5068	7.8640
	Beech – Bukva	–0.7010	3.26234	1.000	–8.5935	7.1914
Beech – *Bukva*	Poplar – Topola	0.3796	3.35667	1.000	–7.7410	8.5003
	Spruce – Smreka	0.7010	3.26234	1.000	–7.1914	8.5935
Chainsaw, I *Motorna pila, I*	Chainsaw, J *Motorna pila, J*					
346 XP	357 XP	–28.3683(*)	3.39245	0.000	–36.5755	–20.1611
	372 XP	0.2283	3.23457	1.000	–7.5969	8.0536
357 XP	346 XP	28.3683(*)	3.39245	0.000	20.1611	36.5755
	372 XP	28.5967(*)	3.39245	0.000	20.3895	36.8039
372 XP	346 XP	–0.2283	3.23457	1.000	–8.0536	7.5969
	357 XP	–28.5967(*)	3.39245	0.000	–36.8039	–20.3895

Table 3 Frequency-unweighted vibration acceleration (rms) in m/s^2
Tablica 3. *Frekvencije nevrednovanih ubrzanja* (m/s^2)

		Husqvarna 346 XP				Husqvarna 357 XP				Husqvarna 372 XP			
Tree species *Vrsta stabala*	Handle *Ručka*	Mean *Arit. sred.*	Sd *Stand. dev.*	Min *Min.*	Max *Maks.*	Mean *Arit. sred.*	Sd *Stand. dev.*	Min *Min.*	Max *Maks.*	Mean *Arit. sred.*	Sd *Stand. dev.*	Min *Min.*	Max *Maks.*
Poplar *Topola*	Front – *Prednja*	51.98	4.05	47.60	56.50	[1]	–	–	–	52.08	3.29	47.70	56.10
	Rear – *Stražnja*	76.10	5.18	70.70	83.60	107.68	6.41	99.40	117.00	72.54	5.55	64.90	78.90
Spruce *Smreka*	Front – *Prednja*	49.10	2.04	46.40	51.00	65.74	2.92	61.90	68.50	49.08	2.27	46.10	51.60
	Rear – *Stražnja*	74.45	6.40	67.20	82.70	121.60	9.96	110.00	137.00	71.68	9.53	63.50	87.40
Beech *Bukva*	Front – *Prednja*	53.78	1.79	52.40	56.90	57.28	3.81	53.20	61.30	55.36	3.86	49.00	59.20
	Rear – *Stražnja*	78.10	3.43	75.30	83.30	109.30	8.42	98.50	117.00	81.60	8.17	71.30	89.30

[1] Values were excluded because of damaged mounting clip – *Izostavljene vrijednosti zbog oštećenja ugrađenih spojnica*

Table 4 Bonferroni's test for frequency-weighted vibration
Tablica 4. *Bonferronijev test za frekvencije vrednovanih ubrzanja*

Tree species, I *Vrsta stabala, I*	Tree species, J *Vrsta stabala, I*	Mean Difference, I–J *Glavna razlika, I–J*	Std. error *Standardna pogreska*	Sig. *Značajno*	95% Confidence Interval *95 % interval pouzdanosti* Lower Bound *Donja granica*	 Upper Bound *Gornja granica*
Poplar – *Topola*	Spruce – *Smreka*	0.0886	0.15478	1.000	–0.2858	0.4630
	Beech – *Bukva*	–1.4969(*)	0.15355	0.000	–1.8684	–1.1254
Spruce – *Smreka*	Poplar – *Topola*	–0.0886	0.15478	1.000	–0.4630	0.2858
	Beech – *Bukva*	–1.5855(*)	0.14924	0.000	–1.9466	–1.2245
Beech – *Bukva*	Poplar – *Topola*	1.4969(*)	0.15355	0.000	1.1254	1.8684
	Spruce – *Smreka*	1.5855(*)	0.14924	0.000	1.2245	1.9466
Chainsaw, I *Motorna pila, I*	Chainsaw, J *Motorna pila, J*					
346 XP	357 XP	–0.3283	0.15519	0.108	–0.7038	0.0471
	372 XP	0.9550(*)	0.14797	0.000	0.5970	1.3130
357 XP	346 XP	0.3283	0.15519	0.108	–0.0471	0.7038
	372 XP	1.2833(*)	0.15519	0.000	0.9079	1.6588
372 XP	346 XP	–0.9550(*)	0.14797	0.000	–1.3130	–0.5970
	357 XP	–1.2833(*)	0.15519	0.000	–1.6588	–0.9079

Table 5 Frequency-weighted vibration acceleration (rms) in m/s^2
Tablica 5. *Frekvencije vrednovanih ubrzanja* (m/s^2)

		Husqvarna 346 XP				Husqvarna 357 XP				Husqvarna 372 XP			
Tree species *Vrsta stabala*	Handle *Ručka*	Mean *Arit. sred.*	Sd *Stand. dev.*	Min *Min.*	Max *Maks.*	Mean *Arit. sred.*	Sd *Stand. dev.*	Min *Min.*	Max *Maks.*	Mean *Arit. sred.*	Sd *Stand. dev.*	Min *Min.*	Max *Maks.*
Poplar *Topola*	Rear – *Stražnja*	4.02	0.29	3.70	4.40	[1]	–	–	–	3.46	0.21	3.20	3.70
	Front – *Prednja*	4.92	0.62	4.40	5.90	5.88	0.34	5.50	6.40	4.06	0.32	3.60	4.40
Spruce *Smreka*	Rear – *Stražnja*	3.78	0.31	3.50	4.20	4.28	0.30	4.10	4.80	3.42	0.51	2.80	4.20
	Front – *Prednja*	4.95	0.79	4.30	6.10	5.66	0.81	5.20	7.10	4.38	1.26	3.50	6.60
Beech *Bukva*	Rear – *Stražnja*	6.34	0.57	5.50	7.10	5.24	0.37	4.70	5.70	4.38	0.49	4.00	5.20
	Front – *Prednja*	7.38	0.65	6.80	8.40	6.64	0.42	6.10	7.20	5.84	1.21	4.90	7.90

[1] Values were excluded because of damaged mounting clip – Izostavljene vrijednosti zbog oštećenja ugrađenih spojnica

3.2 Wood density impact on frequency-weighted HAV – *Utjecaj gustoće drva na frekvencije vrednovanih ubrzanja u sustavu šaka–ruka*

Differences in frequency-weighted vibration acceleration between beech and poplar, as well as, between beech and spruce have been verified by Bonferroni's test (Table 4) and are also shown in the measurement results (Table 5). These findings might be explained by differences in wood density and wood structure, respectively. However, vibration values of poplar and spruce were not found statistically different, despite the fact of comparing a coniferous with a deciduous species. These investigations supported the assumption that wood density alone and independent of the species, has an impact on HAV. Spruce and poplar had

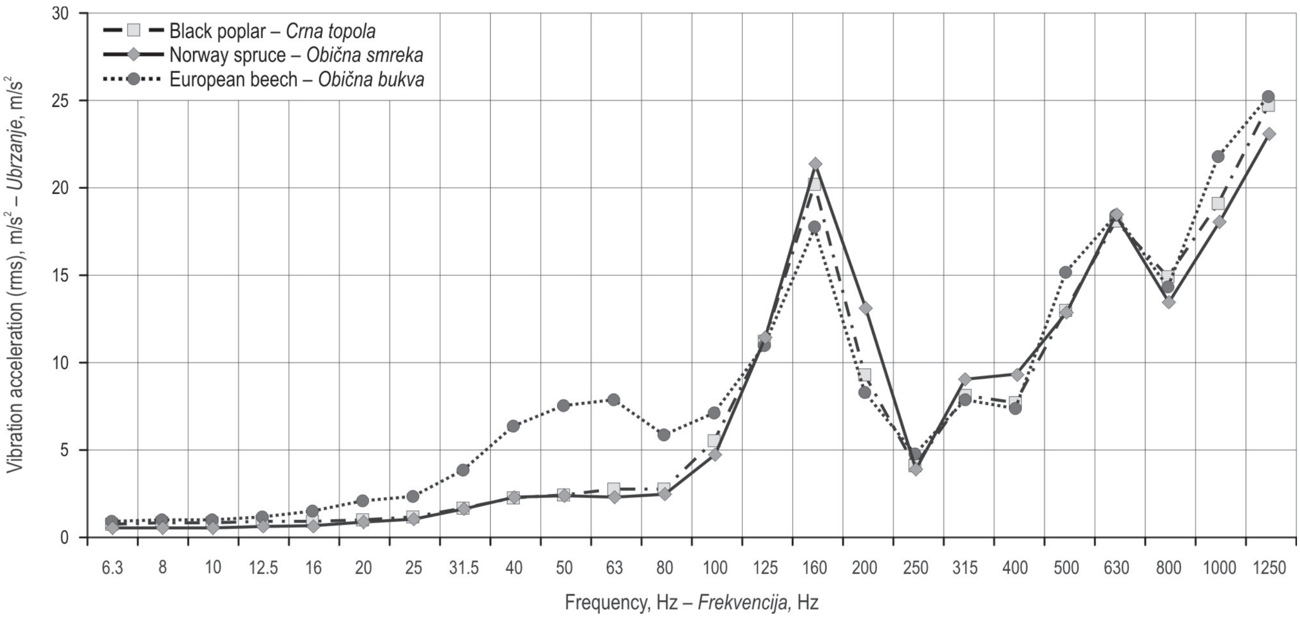

Fig. 3 Frequency-unweighted vibration acceleration for Husqvarna 346 XP for different tree species

Slika 3. *Frekvencije nevrednovanih ubrzanja za motornu pilu Husqvarna 346 XP i različite vrste drva*

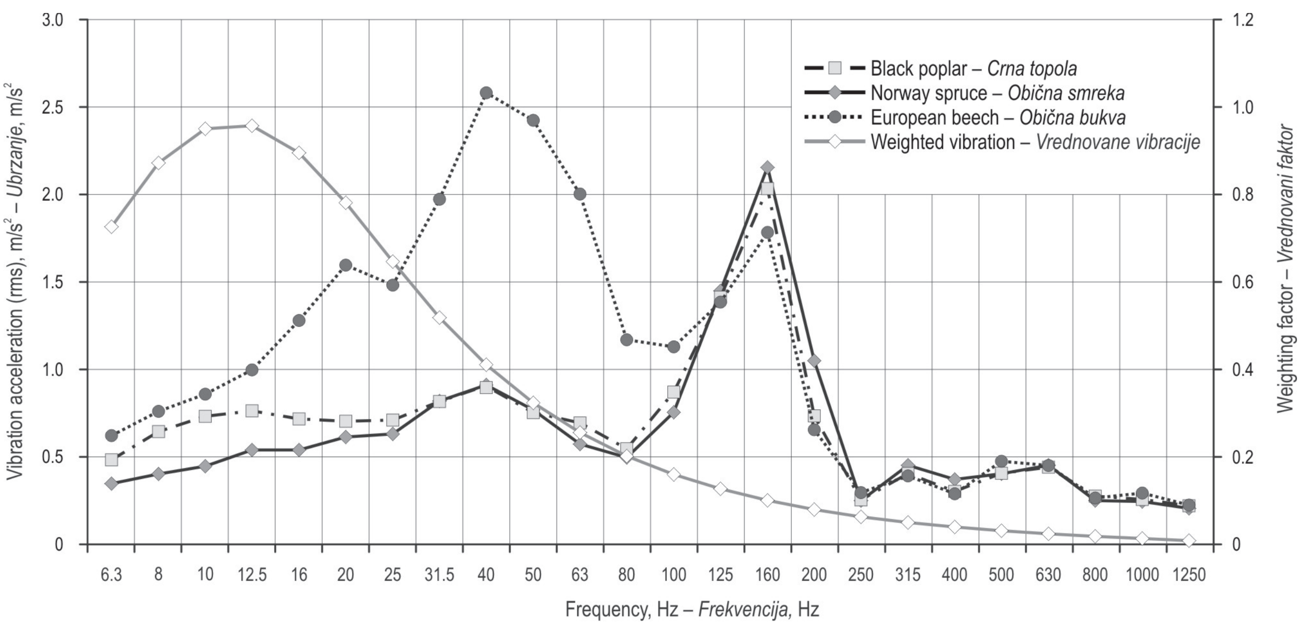

Fig. 4 Frequency-weighted vibration acceleration for Husqvarna 346 XP and weighting factor for HAV

Slika 4. *Frekvencije vrednovanih ubrzanja za motornu pilu Husqvarna 346 XP i vrednovani faktor u sustavu šaka–ruka*

comparable wood density (360 kg/m^3 and 400 kg/m^3, respectively), while that of beech was almost twice as high (700 kg/m^3).

The obvious discrepancy between weighted and unweighted vibration values appeared at first glance, as presented for the chainsaw Husqvarna 346 XP in Fig. 3. Vibration in the beech sawlogs had higher values in the lower frequency range (6.3–100 Hz) than the other two species. Nevertheless, these were just minor differences in the absolute values. The absolute values are equal to the area below the graphs, and this applied for all three species of comparable level. However, major differences were evident between the observed tree species with regard to frequency-weighted vibration, due to the fact that the application of the weighting-filter W_h rates the lower frequencies as more important than the higher ones (Fig. 4).

The weighted vibration mean values regardless of tree species were found to be 5.21 m/s², 5.54 m/s², and 4.26 m/s², respectively, for Husqvarna 346 XP, Husqvarna 357 XP and Husqvarna 372 XP. Post-hoc analysis showed the difference only between Husqvarna 372 XP and the other two chainsaws. The reason probably lies in the fact that Husqvarna 346 XP had the highest frequency-weighted vibration values for beech. For instance, if one just compares the mean values of measurements on spruce (4.27 m/s² for Husqvarna 346 XP, 4.97 m/s² for Husqvarna 357 XP and 3.90 m/s² for Husqvarna 372 XP), the same results appear as for frequency-unweighted vibration (no differences between Husqvarna 346 XP and Husqvarna 372 XP). Anyway, the main focus of this study was to reveal potential differences between tree species and density, respectively, which was found for all observed chainsaws.

4. Discussion – *Rasprava*

The experiment revealed that wood density influences the magnitude of weighted vibration, while no differences in total values for unweighted HAV were found. This is due to differences in the frequency range where vibration appeared. Lower frequencies are weighted by higher factor values because of resonance characteristics of the human body. Vibration acceleration in spruce and poplar in the range of 6.3 to 100 Hz (one-third-octave band center frequencies) were lower than that of beech. On the contrary, in the frequency range greater than 100 Hz, vibration acceleration of spruce and poplar had slightly higher magnitudes than that of beech. This is assumed to be caused by differences in wood density and wood structure, respectively.

Modulus of elasticity might explain these differences along the frequency spectrum. It is 8.9 kN/mm² for poplar, 11 kN/mm² for spruce and 14.4 kN/mm² for beech (Sell 1997). Sound velocity in different wood species can be derived by dividing the species modulus of elasticity by its density, and by taking the square root of that quotient (Burmester 1965). The radial sound velocity is increasing, as wood density increases, a fact that is directly correlated to higher resonance frequencies. Buksnowitz (2006) measured the resonance frequency in radial direction of spruce (*Picea abies*) with an average of 63.25 Hz (minimum 39.60 Hz, maximum 79.74 Hz). These facts might explain the existence of local maximum values for spruce, at a one-third-octave band with center frequency of 50 Hz. In beech and poplar these peak values appeared at 63 Hz, probably due to higher wood density. The higher vibration amplitude of beech was probably due to inferior damping characteristics of higher wood density (Holz 1973). However, as wood resonance is affected by various parameters other than density and modulus of elasticity (Buksnowitz 2006), it could be assumed that differences in frequency-response curves were due to structural differences in wood species.

Wood density impact on weighted HAV was found statistically significant for all three chainsaws. The frequency spectra were pretty much the same for all saws according to the chainsaw engine characteristics. Differences were found with regard to vibration magnitude. Peak values and harmonic components appeared at 160 Hz (engine speed 9.600 rotations per minute, i.e. the maximum power speed for all three saws according to manufacturer's declaration), 320, 640 and 1280 Hz, respectively. Statistical analysis for frequency-unweighted vibration showed no differences between Husqvarna 346 XP and Husqvarna 372 XP. Medium sized Husqvarna 357 XP showed the highest vibration values. For frequency weighted-vibration that relationship could only be measured for spruce. Using all measurements regardless of the tree species only Husqvarna 372 shows differences compared to the other two chainsaws. With respect to the manufacturer's vibration emission declaration in accordance with ISO standard 7505 (ISO 1986), Husqvarna 357 XP has higher values than Husqvarna 346 XP and 372 XP, respectively. Anyway, this is just a comparison of the published mean values without any statistical analysis. Considering this drawback, it cannot be stated if there are any real differences between the published values. Idling speed is the same for all three chainsaws with 2700 rotations per minute according manufacturer's declaration. Rottensteiner and Stampfer (2012) found that frequency-weighted vibrations during idling for all three saws were of comparable level; therefore idling was not included in the statistical model.

According to the Directive 2002/44/EC, employers have to assess the risk of mechanical vibration to which workers are exposed. The assessment of the level of exposure to hand-arm-vibration is based on calculation of the daily vibration exposure value A(8). Daily exposure values are normalized to an eight-hour reference period, which represents the total value of the eight-hour energy equivalent vibration for a worker including all hand-arm vibration exposures during the day. In this study only the influence of wood density on vibration during cutting activities was examined. Nevertheless, this working element counts for around 25% of the total working time (Laier 2011). Therefore, the wood density is also fundamental when calculating the A(8) value. If one reaches the limit value working in a spruce or poplar stand for eight hours, this implicates that vibration exposure for the same worker was above the limit value in a beech stand. Such a case entails a reduction of time performing chainsaw work. In further research, it would be interesting to repeat the experiment in other tree species, work phases (e.g. delimbing), chainsaw types (different manufacturers) as well as different operators.

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Sažetak

Utjecaj gustoće drva na vibracije u sustavu šaka-ruka

Unatoč tehnološkomu napretku i razvoju potpuno strojne sječe, motorne pile lančanice i dalje su najčešći alat pri sječi šuma. U Austriji se 85 % drvnoga obujma (15 milijuna m³) posiječe motornim pilama lančanicama. Dvije najčešće ergonomske prijetnje tijekom sječe motornim pilama lančanicama jest izloženost buci i vibracijama. Provedena su opsežna istraživanja o mjerenju vibracija nastalih tijekom rada s motornom pilom lančanicom, učinku tehnoloških dostignuća na ublažavanje nastalih vibracija na sustav šaka–ruka (HAV), o bolesti bijelih prstiju (VWF), vaskularnih bolesti te mišićno-koštanih poremećaja nastalih zbog izloženosti vibracijama prilikom rada na motornoj pili lančanici.

Međutim, nema istraživanja o povezanosti gustoće drva i izloženosti vibracijama tijekom rada s motornom pilom lančanicom. Različite vrste drva imaju različitu unutarnju građu pa se i očekuju razlike u vrijednostima izmjerenih *vibracija. Izloženost vibracijama mjerena je tijekom sječe crne topole (gustoća suhe tvari 400 kg/m³), obične smreke (gustoća suhe tvari 360 kg/m³) i obične bukve (gustoća suhe tvari 700 kg/m³) na tri modela motornih pila proizvođača Husqvarna, koji su se razlikovali u veličini i snazi. Za simultano mjerenje vibracija u tri međusobno okomita smjera na prednjim i stražnjim ručkama motornih pila lančanica korišten je vibrometar Brüel & Kjaer (troosni akcelerometar 4524-B i LAN-XI 6-kanalni ulaz 3050). Mjerenje i analiza podataka provedeni su u skladu s normama ISO 5349-1 i ISO 5349-2. Obrada podataka učinjena je pomoću računalnoga paketa Brüel & Kjaer Pulse LabShop 14,1.*

Istraživanje mogućih razlika među čimbenicima (gustoća drva, vrsta motorne pile) provedena je uz pomoć analize varijance (ANOVA). Post-hoc analiza za istraživanje moguće razlike između pojedinih vrsta drveća i vrsta motorne pile lančanice učinjena je pomoću Bonferronijeva testa. Rezultati pokazuju da ne postoji razlika ukupne vrijednosti usrednjenih kvadrata (RMS) nevrednovanoga ubrzanja između različitih vrsta drveća.

U svakom slučaju, frekvencijska krivulja bukve razlikuje se od frekvencijskih krivulja topole i smreke. Primjena propusnika iz norme ISO 5349-1 donijela je veće vrijednosti vrednovanoga ubrzanja kod bukve od vrijednosti izmjerenih na topoli i smreci. Nema značajne razlike između topole i smreke. Ovo istraživanje podupire pretpostavku da gustoća drva utječe na vibracije u sustavu šaka–ruka. Izmjerene vibracije bile su više na stražnjoj nego na prednjoj ručki motornih pila lančanica. Razlike između mjerenja na obje ručke (za vrednovano i nevrednovano ubrzanje) statistički su značajne. Nevrednovano ubrzanje izmjereno na motornoj pili lančanici Husqvarna 346 XP na istoj je razini s modelom 372 XP, dok je model 357 XP razvio više vrijednosti ubrzanja.

Gustoća drva također treba biti jedan od temelja pri izračunu dnevne izloženosti radnika vibracijama – A(8). Za procjenu rizika od vibracija nastalih pri radu motornom pilom lančanicom mora se uzeti veća vrijednost (mjerenje na stražnjoj ručki). Vrijednosti su se kretale, ovisno o vrsti motorne pile, od 4,06 m/s² do 4,92 m/s² kod topole, 4,38 m/s² do 5,66 m/s² kod smreke i 5,84 m/s² do 7,38 m/s² kod bukve. Razlike u vibracijama između različitih vrsta drveća koje imaju i različitu gustoću drva nastaju zbog povezanosti značajki rezonatnosti drva i vlage u drvu s gustoćom drva i modulom elastičnosti.

Ključne riječi: motorna pila lančanica, gustoća drva, vibracije, topola, smreka, bukva

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