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RELATIONS BETWEEN TOP-PLATE FILING ANGLE VALUES OF CUTTING CHAINS AND CHAIN SAW VIBRATION LEVELS

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Abstract. The investigations were conducted on 21 BP Oregon cutting chains, with five top-plate filing angle values: 20°, 25°, 30°, 35° and 40°. The chain saw was a 254 Husqvarna model with an Oregon 15” bar. The vibration measurements were conducted while cross-cutting pine logs, and they were performed according to the PN-91/N-01352 [1991] standard. For each of the angles tested 36 measurements were carried out (18 measurements on the front handle and 18 on the rear one). The investigations proved statistically significant differences in vibration levels between different top-plate filing angle values. Apart from that, significant differences were found between vibration levels on different handles and in different measurement axes (x, y, z). The lowest vibration levels were found with chains with extreme top-plate filing angles (20° and 40°). Statistically significant relations between top-plate filing angles and vibrations levels were also found for the front handle in the x and z axes and for the rear handle in the x and y axes.

Key words: chain-saw, cutting chain, vibrations, edge geometry

INTRODUCTION

Wood harvesting activities carried out in motor-manual technologies (with chain-saws) are characterized by a number of loads affecting the workers who perform the work. One of the important loads is the physical one, which often exceeds the physiological standards [Sowa et al. 2006]. A considerable physical work load results not only from working with a chain-saw, but also due to other complementary activities like carrying heavy wood assortments.

As investigations conducted by Stempski and Grodecki [2007] show, the specific energy consumption for operations carried out with a chain saw (felling, delimbing and cross cutting) slightly exceeds the permanent body efficiency limit [Löffler 1990], but the proportion of the work done with a chain-saw reaches 60% of the work-shift time. The work of a chain saw operator is characterised not only by a large physical load and

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high accident risk, but it also may also jeopardize his health in other ways, of which vibrations and noise are most important. Longer exposures to vibrations may lead to diseases with disorders of blood vessel, bones and joints [Wójcik 1998]. An efficient measure which can prevent negative effects resulting from noise is the use of hearing protective equipment, which is already a common practice today. The negative impact of mechanical vibrations caused by chain saws is more difficult to reduce. The best method to do this is to limit the work-time spent with a chain saw, so that the total exposure to the vibration energy will not exceed the equivalent calculated for the weighted acceleration of vibrations, equal to 2.8 $m \cdot s^{-1}$ for the eight-hour work-shift [Wójcik 1998, 2002].

Mechanical vibrations in a chain saw are mainly caused by the back-and-forth movement of the piston, and to a lesser extent by the cutting chain. The latter causes vibrations due to varying forces affecting the cutters which penetrate the wood [Wójcik 2002]. These forces are causes by the resistance of the wood to cutting, which depends on a number of reasons, like the shape and condition of the cutters [Bieńkowski 1993, Maciak 1998, 1999]. The vibration levels resulting from the cutting chain working in the wood depend on the place (front or rear handle) and the direction (x, y, z asis) of the measurement [Sowa 1989]. Sowa [1998] stresses the importance of two other factors that affect the vibration levels, namely the pushing force applied to the saw and gauge depths of the cutters, which have a direct effect on the resistance of wood to cutting. Another factor which affects the vibrations emitted by chain saws is the way the operators work with these machines. This problem was studied by Skarżyński [2007], who tested vibration levels when cutting wood logs of different diameters with the upper and lower sides of the bar. His results proved that both the working techniques as well as the wood log diameters significantly affected the vibrations.

The majority of studies on modern cutting chains focus on the effects of different factors on the basic operational parameter, namely the specific cutting efficiency [Górski 1996, Komorowski 1987]. Relatively little is known on the effect of the top-plate filing angle on the cutting of wood and on the vibration levels caused by the saw. The problem can also be interesting from a practical point of view, as this angle can easily be changed by unskillful sharpening of the cutting chain.

The purpose of the investigation was to measure the vibration levels caused by a chain saw, when cross-cutting wood with chains with different top-plate filing angles. The angles were tested at 5° intervals, from 20° to 40°. The tests were run on chains with semi-chisel cutters.

METHODS

The tests were conducted on five 21 BP Oregon chain saws which differed in the value of the top-plate filing angle. The angles were 20°, 25°, 30°, 35° and 40° and they were put on a 15" Oregon bar of a Husqvarna chain saw.

The investigations were carried out while cross-cutting debarked pine logs, 24-26 cm in diameter. Nine logs were put on stands about 1.2 m above the ground and they were numbered. The operation of cross-cutting was carried out by a chain saw operator, who cut off three cm thick wood discs. Places with visible knots were skipped and in case of deeper knots, revealed after the disc had been cut off, the cutting and measuring procedures were repeated. The measurements were done according to the PN-91/N-01352:1999 standard. The measuring device was Robotron 1300 and it was used to take 18 measurements on the front and rear handles of the saw (two discs on each log).

The wood which was used in the investigation was subject to further analysis aiming to determine the proportion of hard and late wood on discs, broken down to groups which consisted of discs cut off with chains with the same top-plate filing angles. The assessment of the hard wood was carried out based on eight measurements covering the disc diameter and the diameter of hard wood visible on the cross section. These measurements were taken on 135 discs, in 15 groups of 9 discs, and the total number comprised all the cut off discs cut with all the tested chains. The shares of the hard wood in the grouped discs were put to statistical analysis.

The participation of late wood in the wood discs was assessed based on width measurements of the late wood zones in the yearly rings. The measurements were carried out with an electronic increment meter, along the radius, which was oriented in the same direction on each of the discs. The measurements were taken on 36 discs, in 4 groups of 9. Like in the case of the hard wood assessment, the statistical analysis of the measurement results focused on testing the significance of differences between late wood shares in different disc groups.

RESULTS

In order to assess the differences in the proportion of the hard and late wood in the groups of wood discs which were cut off with chains with different top-plate filing angles the one-factor analysis of variance was used. The results that were obtained showed no statistically significant differences between average proportions of both hard, as well as late wood in the groups of discs which were cut off with the tested chains.

The average acceleration values of vibrations and their variability characteristics are presented in Table 1. The results varied not only due to the top-plate filing angle values but were also affected by the handle and direction in which they were measured. The vibration acceleration values on the front handle varied between 1.9 and 4.8 $m \cdot s^{-1}$, while on the rear handle the vibration values were higher and varied between 2.8 and 6 $m \cdot s^{-1}$. The highest values recorded on the front handle were measured in the x-axis direction. In the case of the rear handle the highest vibration values were recorded in the x-axis direction, while the lowest values were measured in the y-axis direction, regardless of the top-plate angle.

The largest variability of the vibration acceleration values on the front handle were recorded for the 25°, 35° and 40° angles for the x axis, for the 30° angle for the y axis, and for the 20° angle for the z axis, where the variability coefficient exceeded 40%.

On the rear handle, the largest vibration acceleration values for the 25° and larger angles were recorded for the x axis, and for the 20° angle – for the z axis.

The average vibration acceleration values from Table 1 are larger for the rear handle compared to the front one. The differences vary from several to more that ten per cent, but for the x axis for all the tested angles (for 20° also for z axis) the differences exceeded 100%. The significance of differences between the vibration values on the rear and front handles were tested with the t-Student test, with a prior variance testing.

Table 1. Average vibration acceleration values
Tabela 1. Średnie wartości przyspieszeń drgań

Angle Kąt	Axis Oś	Front handle – Uchwyt kabłąkowy average średnia $m \cdot s^{-1}$	standard deviation odchylenie standardowe $m \cdot s^{-1}$	coefficient of variability współczynnik zmienności %	Rear handle – Uchwyt sterowniczy average średnia $m \cdot s^{-1}$	standard deviation odchylenie standardowe $m \cdot s^{-1}$	coefficient of variability współczynnik zmienności %
20°	x	2.0	0.19	9.55	5.8	0.67	11.58
	y	4.0	0.28	7.00	2.8	0.31	10.84
	z	2.6	0.31	44.62	5.5	0.66	11.99
25°	x	2.8	0.43	15.47	7.7	2.32	30.06
	y	3.8	0.35	9.26	4.7	0.63	13.35
	z	3.9	0.47	12.04	4.8	1.08	22.34
30°	x	2.3	0.57	24.52	5.4	1.26	23.29
	y	4.8	1.44	29.83	5.2	0.60	11.53
	z	4.8	0.56	11.62	5.5	0.55	10.02
35°	x	1.9	0.47	24.67	6.1	1.91	31.53
	y	4.0	0.69	17.26	4.2	0.48	11.65
	z	4.6	0.71	15.32	6.0	0.89	14.87
40°	x	1.9	0.31	16.47	4.8	1.46	30.44
	y	3.8	0.57	15.07	4.1	0.53	13.02
	z	3.7	0.39	10.49	5.4	0.47	8.71

The results presented in Table 2 showed that the differences between the results recorded on the two handles were statistically significant. In three cases only no differences were found, and they all concerned the 30°, 35° and 40° in the y axis.

As the basic aim of the investigation was to test the impact of the top-plate filing angle on vibration acceleration, the average acceleration values measured for different angles were put statistical analysis. The significance of differences was tested for each of the measurement directions (x, y, and z axes), for the front and rear handles. The one-factor analysis of variance procedure was used for that purpose and the analysis results are presented in Table 3. The data in this table shows that different top-plate filing angles had statistically significant effects on vibration values when cross-cutting wood.

Different vibration values measured on chains with different angles suggest relations between these traits. In order to see how strong they were the Pearson's correlation coefficients were calculated and the relations between the investigated traits were described with regression lines. Then, the statistical significance of the relations between the top-plate filing angles and the vibration levels were tested. The results, which are presented in Table 4 show weak or none relations between the analysed traits. The lowest correlation coefficient values – lower than 0.2 – were found for measurements carried out in the y direction on the front handle and in the z direction on the rear handle.

Table 2. Difference test results between vibration values on the rear and front handles
Tabela 2. Wyniki testu istotności różnic wibracji na uchwytach pilarki

Angle Kąt	Axis Oś	Student *t* test Test *t* Studenta		Difference Różnica
		calculated *t* value wartość statystyki *t*	critical value wartość krytyczna $t_{0,05}$	
20°	x	23.232	2.270	+
	y	–11.584	2.034	+
	z	16.562	2.567	+
25°	x	8.830	2.181	+
	y	5.632	2.750	+
	z	3.263	2.516	+
30°	x	9.467	2.546	+
	y	1.055	14.267	–
	z	3.671	2.034	+
35°	x	8.948	2.241	+
	y	0.783	2.034	–
	z	4.961	2.034	+
40°	x	8.312	2.200	+
	y	1.583	2.034	–
	z	11.462	2.034	+

+ – difference statistically significant.
– – no statistically significant difference.
+ – różnica statystycznie istotna.
– – brak statystycznie istotnej różnicy.

Table 3. Results of the analysis of variance for average vibration values of the chain-saws tested
Tabela 3. Wyniki analizy wariancji średnich wartości drgań badanych pił łańcuchowych

Handle Uchwyt	Direction of measurement Kierunek pomiaru	F value Wartość statystyki *F*	Critical value Wartość krytyczna $F_{0,05}$
Front Kabłąkowy	x	16.630	2.479
	y	5.843	
	z	52.490	
Rear Sterowniczy	x	8.251	2.479
	y	53.203	
	z	5.082	

In these two cases the relation between the top-plate filing angle and the acceleration of vibrations was statistically insignificant, in all the other cases however, this relation, although weak was statistically significant.

As the data presented in Table 4 shows, increasing the top-plate filing angle values led to falling vibrations levels in the x and y directions on the front handle, while in the z measurement axis the vibration values rose. On the rear handle a different effect was observed, vibration levels measured in the x direction fell with the rise of the angle, but they increased when measured in the other two directions.

Table 4. Correlation and regression lines for relations between top plate filing angles and vibration values
Tabela 4. Korelacja i regresja kątów nachylenia ostrza poziomego z poziomem wibracji

Handle Uchwyt	Direction of measurement Kierunek pomiaru	Correlation coefficient Współczynnik korelacji	Regression equasion Równanie regresji	Relation Zależność
Front Kabłąkowy	x	–0.2876	Y = 2.8289 + (–0.0218)X	+
	y	–0.0246	Y = 4.1533 + (–0.003)X	–
	z	0.4474	Y = 2.2111 + 0.0582X	+
Rear Sterowniczy	x	–0.2728	Y = 8.1 + (–0.0718)X	+
	y	0.2801	Y = 3.0656 + 0.0377X	+
	z	0.1695	Y = 4.844 + 0.0198X	–

+ – difference statistically significant.
– – no statistically significant difference.
+ – zależność statystycznie istotna.
– – brak statystycznie istotnej zależności.

A parameter that characterises vibrations is the maximum value of vector sums of effective, frequency weighted accelerations of vibrations measured in three directions on the front and rear handles. Its value, compared with the limit specified in relevant standards enables to calculate the maximum work-time with a given chain saw model [Więsik and Wójcik 2002].

The average vector sums of vibration accelerations presented in Table 5 are high and they vary between 8.5 and 20.5 $m \cdot s^{-1}$. The highest value was found for the 25° angle, and the values for the 30° and 35° angles were about 1 $m \cdot s^{-1}$ lower. The lowest values of vector sums were found for the extreme top-plate filing angle values – 20° and 40°. The highest variability coefficient was found with the 25° angle, the lowest – for the 20° angle.

In order to see if the average vector sums of vibration accelerations measured for different top plate angles were statistically different, the one-factor analysis of variance was conducted. Its results showed that such differences did exist and Tukey's test (T method) found them for the following angle pairs: 20° and 25°, 20° and 35°, 25° and 40°, 35° and 40° (Fig. 1).

Table 5. Basic characteristics of vector sums for vibration acceleration values
Tabela 5. Podstawowe charakterystyki sum wektorowych przyspieszeń drgań

Angle Kąt	Average Wartość średnia $m \cdot s^{-1}$	Standard acceleration Odchylenie standardowe $m \cdot s^{-1}$	Coefficient of variability Współczynnik zmienności %
20°	8.5	0.55	6.52
25°	10.4	1.66	15.84
30°	9.4	1.06	11.34
35°	9.6	1.12	11.64
40°	8.4	1.09	13.07

	40°	20°	30°	35°	25°
$\bar{x}$	8.4	8.5	9.4	9.6	10.4
40°		–	–	+	+
20°			–	+	+
30°				–	–
35°					–

Fig. 1. Cross comparison results of vector sums for the angles tested: $\bar{x}$ – average vector sum values for vibration acceleration values, + – difference statistically significant, – – no statistically significant difference
Rys. 1. Wyniki porównania średnich sum wektorowych każdego kąta z każdym: $\bar{x}$ – średnie wartości sum wektorowych przyspieszeń drgań, + – różnica statystycznie istotna, – – brak statystycznie istotnej różnicy

CONCLUSIONS

1. The investigations showed statistically significant differences between the vibration levels and the top plate filing angle values, the place of measurement and the measurement direction.
2. Vibration levels measured on the front handle in the x and z directions and on the rear handle in the x and y directions showed strong relations with the top-plate filing angles. The relations were weak but statistically significant.
3. The effective weighted acceleration values of vibrations (vector sums from three directions) observed on the cutting chains used in the investigations strongly exceeded the limit set for permanent eight-hour work.
4. Statistically significant effects of top plate filing angles on vibration levels require checking this angle when using cutting chains.
5. Vibration level tests suggest that it is possible to use other top plate filing angles than the 30° angle, specified by the manufacturer. Vibration levels are not the decisive factor when choosing the 30° angle as the optimum one for semi-chisel cutting chains.

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ZALEŻNOŚĆ MIĘDZY WIELKOŚCIĄ KĄTA NACHYLENIA KRAWĘDZI TNĄCEJ OSTRZA POZIOMEGO PIŁY ŁAŃCUCHOWEJ A EMISJĄ DRGAŃ PILARKI

Streszczenie. Badaniami objęto piły łańcuchowe firmy Oregon o symbolu 21 BP. Jednostką napędową była pilarka Husqvarna 254 z 15" prowadnicą Oregon. Zastosowano pięć kątów nachylenia krawędzi tnącej ostrza poziomego: 20°, 25°, 30°, 35° i 40°. Pomiary wykonano podczas przerzynki kłód sosnowych, postępowano zgodnie z wymogami określonymi w PN-91/N-01352 [1991]. Dla każdego kąta nachylenia ostrza wykonano po 36 pomiarów (po 18 na uchwycie kabłąkowym i sterowniczym). W badaniach wykazano statystycznie istotne różnice w poziomie drgań mechanicznych w zależności od wielkości kąta nachylenia krawędzi tnącej ostrza poziomego. Różnice takie stwierdzono także między uchwytami pilarki i kierunkami pomiaru (oś x, y, z). Najmniejsze wartości przyspieszeń drgań odnotowano w przypadku pił ze skrajnymi wartościami kątów nachylenia ostrza (20° i 40°). Statystycznie istotny związek między wielkością kąta nachylenia ostrza a poziomem emitowanych drgań odnotowano na uchwycie kabłąkowym w kierunku pomiaru x i z, a na uchwycie sterowniczym na kierunku x i y.

Słowa kluczowe: pilarka, piła łańcuchowa, drgania, geometria ostrza

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