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EFFECT OF THE EDGE GEOMETRY IN A CUTTING CHAIN ON THE CHAIN SAW VIBRATION LEVEL

Włodzimierz Stempski, Krzysztof Jabłoński, Jarosław Wegner
Poznań University of Life Sciences

Abstract. Vibration levels were measured while cross-cutting pine wood logs. In the experiment five chisel type cutting chains, with a 0.325" pitch were used. The chains differed in the top-plate filing angle which had the following values: 20º, 25º, 30º, 35º and 40º. The cross-cutting was performed by a chain saw operator. The measurements were carried out on the front and rear handles in the x, y and z axes. There were 18 measurements for each top-plate filing angle on each of the handles. The Robotron M1300 meter was used. Considerably higher vibration levels were observed on the rear handle. The effect of the top-plate filing angle on the mechanical vibrations was statistically significant. The correlation between the angle and the vibration value showed a weak relation, but it was statistically significant in those cases in which it appeared.

Key words: chain saw, vibrations, cutting edge geometry

INTRODUCTION

Chain saws are basic machines used for cutting wood. Despite a noticeable increase in the number of harvesters observed in recent years, about 90% of wood is cut with chain saws every year [Kusiak 2008].

Work performed with a chain saw belongs to the most arduous category, with a considerable physical effort [Sowa et al. 2006, Stempski and Grodecki 2005]. Working with a chain saw poses high health risk for the operator due to vibration, noise and exhaust gas emissions. A prolonged exposure to vibrations may lead to negative health effects, called the vibration syndrome. These effects apply mainly to hands and arms, leading to blood vessel disorders, causing a deterioration in blood penetration into hands and irrevocable changes in bones and joints [Wójcik 1998].

Chain saws that are used today are characterised by considerably lower vibration levels than models which were used a few decades or even years ago, however it is not possible to completely eliminate vibrations emitted by chain saws [Sowa and Leszczyński 2000]. The basic source of vibrations in a chain saw is its engine, and the reciprocat-

Corresponding author – Adres do korespondencji: Dr W. Stempski, Department of Forest Technology of Poznań University of Life Sciences, Wojska Polskiego 71 C, 60-625 Poznań, Poland, e-mail: stempski@up.poznan.pl

ing movement of the piston in particular. Apart form that, vibrations are caused by the cutting chain, which in the course of cutting is exposed to variable loads [Wójcik 2002]. The level of vibrations emitted by the chain saw depends on many factors, among them the technical condition of the machines plays an important role [Ciesielczuk et al. 1998]. As experiments by Sowa [1998] have shown, the vibration level most significantly depends on the measurement direction (x, y, z) and on which handle (front or rear) it is measured. He also underlines the considerable effect of the pushing force exerted on the machine and that of the cutting link gauge depth on the vibration levels [Sowa 1998]. The value of the pushing force is strongly dependant on the working technique and the gauge depth is determined by the manufacturer. Unfortunately, in practical conditions chain saws are rarely used in accordance with the recommendations set by the manufacturers. For example, a survey by Trzciński [1995] showed that only 15% of chains had the proper gauge depths.

At present there is a host of different cutting chains available on the market, and the efforts of the manufacturers are directed into increasing work safety. As a result, there are chains available with low-kickback bumper drive links and bumper tie-straps, as well as chains equipped with vibration reducing links [Wójcik 2008].

Effects of various factors on basic wood cutting parameters with cutting chains have been analysed by a number of researchers [Bieńkowski 1993, Maciak 1998, 2000, Kozłowski 2002, 2003]. However, relations between the geometry of cutting edges of the cutters and the vibration levels have been poorly studies so far.

The purpose of this experiment was to analyse the effect of the top-plate filing angle on vibrations emitted when cross-cutting pine wood. The vibrations were measured for angles from 20° to 40°, and the experiments were carried out on chisel type cutting chains.

MATERIAL AND METHODS

The experiments were carried out with five Oregon 21LP cutting chains. The chains differed in top-plate filing angle values (20°, 25°, 30°, 35° and 40°). The chains were mounted on a Husqvarna 254 chain saw with a 15" bar.

The vibration levels were measured during the operation of cross-cutting, on nine fresh, debarked pine logs with 24-26 cm diameters. The logs were placed 120 cm above the ground and during the cross-cutting 3 cm thick wood discs were cut off. The discs were numbered with two digits, the first digit denounced the disc number and the other the log number (e.g. 1/1 – disc 1 on log 1; 1/2 – disc 1 on log 2).

The cross-cutting was carried out by the saw operator and the engine speed was controlled with the help of an electronic tachometer DET-302. The acceleration of the mechanical vibrations was measured with the Robotron M1300 meter. The measurements were carried out according to the Polish Standard (PN-91/N-01352 1992), on the front and rear handles in the x, y and z axes. There were 18 measurements per each handle, 2 measurements on each log. First, the vibrations were measured on the front handle, then on the rear handle. In case there were knots in measurement area on the log, the measurement was repeated.

In order to check the homogeneity of the wood used for the experiments, the proportions of the heart-wood and the late wood in the wood disc groups were determined.

The share of the heart-wood was determined based on the total wood disc and the heartwood area diameters. There were 8 measurements per one wood disc and the diameters were measured with an accuracy of 1 mm. The shares of the heartwood were determined for 15 groups consisting of 9 discs each, and for 135 wood discs altogether.

The share of the late wood was determined based on the late wood measurements along the disc radius, related to the total radius length. On each of the discs the radius was oriented in the same direction. The measurements were carried out with an electronic increment meter, with an accuracy of 0.01 mm. The average shares of the late wood were calculated in four groups consisting of 9 wood discs each, and for 36 wood discs altogether. The groups of wood discs were formed by discs cut from the same position on each of the logs, with their first digital markings 1, 5, 10 and 10. The results obtained were statistically analysed.

RESULTS

Participation of heartwood and late wood

The basic features of the shares of the heartwood and late wood are presented in Table 1. The average proportion of the heartwood was 53-54% and only in two cases was it lower than 53%. The average value for all wood discs was 53.7%. The values of the variability coefficients varied from 8 to 12% in the disc groups, whereas the variability coefficient for all the discs reached 9.94%.

Table 1. Heartwood and late wood shares in wood discs
Tabela 1. Udział drewna twardzielowego i późnego w krążkach

Disc Krążek	Heartwood Drewno twardzielowe		Late wood Drewno późne	
	average średnia	coefficient of variability współczynnik zmienności	average średnia	coefficient of variability współczynnik zmienności
1	54.4	11.83	24.9	15.19
2	52.2	11.12		
3	53.5	11.06		
4	54.0	11.12		
5	54.6	11.36	26.8	24.57
6	54.7	11.83		
7	53.4	11.57		
8	53.6	10.42		
9	53.9	9.18		
10	53.4	9.25	25.9	21.33
11	53.4	8.32		
12	52.7	8.53		
13	53.8	9.33		
14	54.6	9.53		
15	53.6	10.67	29.1	18.89

The average proportion of the late wood in the wood used in the experiment was 26.7%, and it varied from 25 to 29% for particular disc groups. The proportion of the late wood was more diversified than that of the heartwood. In particular groups, the variability coefficient varied between 15 and 24%, and its value amounted to 20.37% for all discs altogether.

Table 2. Results of the analysis of variance for the shares of heartwood and late wood
Tabela 2. Wyniki analizy wariancji udziału drewna twardzielowego i późnego

Source of variation Źródła zmienności	Sum of squares Suma kwadratów	Degrees of freedom Stopnie swobody	Variance Wariancja	F value Wartość statystyki F
Heartwood – Drewno twardzielowe				
Total Całkowita	3 821.85	134		
Between groups Między grupami	61.69	14	4.406	0.141
Error Błąd	3 760.16	120	31.335	
Late wood – Drewno późne				
Total Całkowita	1 032.56	35		
Between groups Między grupami	85.93	3	28.642	0.968
Error Błąd	946.63	32	29.582	

In order to see if the participation values of the heartwood and late wood significantly differed between wood disc groups, the one-factor analysis of variance was performed. Its results are presented in Table 2 and they show that the average heartwood and late wood shares in the discs cut off with chains with different top-plate filing angles did not differ significantly.

Vibration acceleration on the front and rear handles

Average values of vibration acceleration for the analysed top-plate filing angles that have been measured in course of the experiment are presented in Table 3. The figures in the table show that acceleration values were varied for different handles, measurement directions and top-plate angle values. The largest vibration values on the rear handle varied between 5.7 and 6.3 $m \cdot s^{-1}$, for all the analysed angles. In the case of the 20° and 25° angles the largest vibration acceleration values were recorded for the X axis, while for the other analysed angles the highest values were recorded for the Z axis. The variability coefficient exceeded 30% for the 20°, 25°, 30° and 40° angles, and only in the case of the 35° angle it was lower than 20%.

On the front handle, that largest average vibration acceleration values were around 4 $m \cdot s^{-1}$ (form 3.6 $m \cdot s^{-1}$ to 4.4 $m \cdot s^{-1}$) and were recorded for the Z axis for all the analysed

Table 3. Basic characteristics of vibration acceleration values
Tabela 3. Podstawowe charakterystyki przyspieszeń drgań

Angle Kąt	Axis Oś	Rear handle Uchwyt sterowniczy			Front handle Uchwyt kabłąkowy		
		average średnia	standard deviation odchylenie standardowe	coefficient of variability współczynnik zmienności	average średnia	standard deviation odchylenie standardowe	coefficient of variability współczynnik zmienności
		$m \cdot s^{-1}$	$m \cdot s^{-1}$	%	$m \cdot s^{-1}$	$m \cdot s^{-1}$	%
20°	x	5.7	2.20	38.58	1.8	0.32	18.03
	y	4.1	0.58	14.33	3.4	0.30	8.69
	z	4.7	0.69	14.66	3.6	0.48	13.28
25°	x	6.1	2.05	33.87	2.2	0.44	20.06
	y	3.9	0.59	14.97	4.0	0.76	18.96
	z	6.0	0.61	10.33	4.4	0.72	16.43
30°	x	5.1	1.58	31.16	2.2	0.37	17.08
	y	3.6	0.37	10.34	3.7	0.56	15.07
	z	6.3	0.81	13.04	4.1	0.66	15.88
35°	x	4.8	0.89	18.78	1.6	0.20	12.26
	y	4.3	0.65	15.14	3.3	0.47	14.48
	z	5.7	0.74	13.10	4.0	0.47	11.72
40°	x	4.3	1.47	34.26	1.6	0.11	6.69
	y	2.8	0.51	18.12	3.4	0.36	10.62
	z	5.8	0.52	8.99	3.6	0.28	7.78

top-plate filing angles. The results obtained were less dispersed than for the rear handle. The highest variability coefficient value was 20%. For the 20°, 25° and 30° angles the highest dispersion of results was recorded for the X axis and for the two remaining angles – 35° and 40° – for the Y axis.

The data presented above shows that the vibration levels on the rear handle were much higher than on the front one. Only in the cases of the 25° and 30° angles were the average vibration values higher on the front handle. In order to see if the differences between the vibration values on the two handles were statistically significant, the t-Student test was carried out. Its results are presented in Table 4 and they show that in the majority of cases the vibrations on the two handles are statistically significantly different. Only in the cases of the previously mentioned 25° and 30° angles, for the Y axis, were the vibration values on the front and rear handles statistically insignificant.

Average vibration values or different top-plate filing angles were also a subject of further statistical analyses. The effect of the top-plate filing angle on the vibrations level were studied by means of the single factor analysis of variance completed separately for the front and rear handles, separately for each of the measurement directions (X, Y, Z axes). The results are presented in Table 5 and they show that both in the case of the

Table 4. Difference test results between vibration values on the rear and front handles
Tabela 4. Wyniki testu różnic między wibracjami na uchwycie sterowniczym i kabłąkowym

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	7.5056	2.151	+
	y	4.1971	2.652	+
	z	5.3934	2.034	+
25°	x	7.7558	2.213	+
	y	0.3445	2.034	–
	z	7.0505	2.034	+
30°	x	7.5246	2.228	+
	y	0.8476	2.034	–
	z	8.5289	2.034	+
35°	x	14.6617	2.204	+
	y	5.3164	2.034	+
	z	7.9744	2.034	+
40°	x	7.7225	2.113	+
	y	4.0428	2.034	+
	z	15.6590	2.716	+

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

Table 5. Results of the analysis of variance for vibration levels at the analysed top-plate filing angles
Tabela 5. Wyniki analizy wariancji poziomów drgań dla analizowanych kątów nachylenia krawędzi tnącej ostrza poziomego

Handle Uchwyt	Direction of measurement Kierunek pomiaru	F value Wartość statystyki F	Critical value Wartość krytyczna $F_{0,05}$
Rear Sterowniczy	x	3.131	2.49
	y	19.059	
	z	13.502	
Front Kabłąkowy	x	16.985	2.49
	y	5.581	
	z	6.555	

front as well as the rear handles, the overall effect of the top-plate filing angle on the vibration level was statistically significant. Statistically significant differences were found for each of the measurement axes.

Statistically significant differences in vibration values at different top-plate filing angles prove that there is a relation between these variables. The strength of this relation was analysed by means of Pearson correlation coefficient and the relation was described with regression equations. The results obtained are presented in Table 6. The correlation values between the top-plate filing angles and the vibration levels on the rear handle varied between 0.3 and 0.4, and between 0.08 and 0.32 of the front handle, which indicates a weak correlation or a complete lack of it. Despite weak correlation values, in the cases where they were found, they were also statistically significant.

Table 6. Relations between top-plate filing angles and vibration acceleration values
Tabela 6. Związki kątów nachylenia ostrza poziomego z wartościami przyspieszeń drgań

Handle Uchwyt	Direction of measurement Kierunek pomiaru	Correlation coefficient Współczynnik korelacji	Regression equasion Równanie regresji	Relation Zależność
Rear Sterowniczy	x	–0.3291	Y = 7.6533 + (–0.0826)X	+
	y	–0.3999	Y = 4.9711 + (–0.0414)X	+
	z	0.3327	Y = 4.4767 + 0.04X	+
Front Kabłąkowy	x	–0.3254	Y = 2.4433 + (–0.0189)X	+
	y	–0.1675	Y = 3.96 + (–0.0133)X	–
	z	–0.0805	Y = 4.1644 + (–0.0069)X	–

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

On the front handle in each measurement direction and on the rear handle in the X and Y directions, the relations between the top-plate filing angles and vibration levels were negative. That means that the vibration level decreased as the top-plate filing angle increased. Only in the case of the rear handle, when measured in the Z direction, did the vibration level rise with an increase in the filing angle.

CONCLUSIONS

1. Values of the vibration acceleration on the rear handle are statistically significantly higher than those on the front handle.
2. Top-plate filing angle values had a statistically significant effect on vibration acceleration values.
3. The relation between the vibration levels and the top-plate filing angle was weak but it was statistically significant in those cases in which it appeared.

4. Increase in the top-plate filing angle values caused, in majority of cases, a statistically significant fall of the vibration acceleration values.

5. The results show, that from the ergonomic point of view the required top-plate filing angle is 40°, as for this angle values the lowest vibration values were measured. The cutting chain manufacturer recommends the 25° angle, for which the highest vibration values were observed. It seems that a reasonable compromise is a 20° angle, which although showed an effective higher weighted vibration acceleration value than the lowest values measured, but it was close to the recommended angle values for a chisel type cutting chains.

REFERENCES

Bieńkowski J., 1993. Wpływ stępienia ostrzy tnących na opory i wydajność skrawania piłą łańcuchową [Effects of the sharpness of cutting chain links on the productivity cutting wood with a chain saw]. Przeg. Tech. Roln. Leśn. 12, 17-20 [in Polish].

Ciesielczuk P., Rydzewski W., Więsik J., 1998. Wpływ stanu technicznego układu napędowego pilarki spalinowej na emisję drgań [Effects of the technical condition of the chain saw driving system on vibration emissions]. Przeg. Tech. Roln. Leśn. 2, 17-19 [in Polish].

Kozłowski R., 2002. Wpływ siły posuwu piły łańcuchowej na powierzchniową wydajność skrawania i zużycie paliwa [Effect of the pushing force applied to the chain saw on the surface cutting productivity and fuel consumption]. Przeg. Tech. Roln. Leśn. 3, 21-23 [in Polish].

Kozłowski R., 2003. Wpływ typu piły łańcuchowej i gatunku drewna na wydajność skrawania i zużycie paliwa [Effects of the cutting chain type and wood species on the cutting productivity and fuel consumption]. Przeg. Tech. Roln. Leśn. 4, 19-21 [in Polish].

Kusiak W., 2008. Tendencje na rynku harwesterów i forwarderów w Polsce [Harvester and forwarder market trens in Poland]. In: Materiały Konferencji "Bezpieczeństwo pracy przy maszynowym pozyskiwaniu i zrywce drewna". Tom 6. XI Targi Gospodarki Leśnej, Przemysłu Drzewnego i Ochrony Środowiska. 4 września 2008. Tuchola, 24-36 [in Polish].

Maciak A., 1998. Wpływ geometrii ostrza żłobikowego na jego obciążenie podczas skrawania drewna sosnowego [Effects of the cutting link geometry on its load during the cutting of pine wood]. Przeg. Tech. Roln. Leśn. 5, 18-21 [in Polish].

Maciak A., 2000. Wpływ zużycia ogniw tnących piły łańcuchowej na wydajność skrawania drewna [Efects of the wear of the cutting links in a cutting chain on the productivity of cutting wood]. Przeg. Tech. Roln. Leśn. 1, 20-22 [in Polish].

Sowa J.M., 1989. Wpływ czynników techniczno-technologicznych na poziom drgań mechanicznych pilarek spalinowych [The influence of technical and technological factors on vibration levels of chain saws]. Zesz. Nauk. AR Krak. 232, 183-190 [in Polish].

Sowa J.M., 1998. Analiza zagrożeń wibracyjnych operatorów pilarek spalinowych [Analyses of the chainsaw vibration hazard of cutters]. Zast. Ergon. 1, 2, 3, 189-196 [in Polish].

Sowa J.M., Leszczyński K., 2000. Zmiany w poziomie zagrożeń operatorów maszyn przy pozyskiwaniu drewna [Changes in threat levels to machine operators in wood harvesting]. In: Materiały III Konferencji Leśnej "Stan i perspektywy badań z zakresu użytkowania lasu". Sękocin Las 30-31 marca 2000. IBL Warszawa, 412-424 [in Polish].

Sowa J.M., Leszczyński K., Szewczyk G., 2006. Human energy expenditure in late thinning performed in mountain spruce stands. Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar. 5(1), 73-80.

Stempski W., Grodecki J., 2005. Effects of work methods on physical load of a logger in wood harvesting operations. Zesz. Nauk. AR Krak. 419, 383-389.

Trzciński G., 1995. Ocena stanu technicznego pilarek spalinowych będących własnością robotników leśnych [Assessment of the technical condition of chain saws owned by forestry workers]. Przeg. Tech. Roln. Leśn. 1, 21-23 [in Polish].
Wójcik K., 1998. Ekonomiczne aspekty oddziaływania na organizm ludzki drgań emitowanych przez pilarki spalinowe przy pozyskiwaniu drewna [Economical aspects of influence of vibrations emitted by chainsaws during logging operations on human body]. Zast. Ergon. 1, 2, 3, 183-188 [in Polish].
Wójcik K., 2002. Metodyka badania drgań i wyznaczania dopuszczalnego dziennego czasu pracy operatora pilarki spalinowej przy pozyskiwaniu drewna [The metodology of investigation into chain saw vibrations and determination of permissible daily worktime of chain saw operator during timber harvest]. Zast. Ergon. 1-4, 223-235 [in Polish].
Wójcik K., 2008. Nowe rozwiązania techniczne układów tnących pilarek przenośnych [New technical solutions in cutting systems in portable chain saws]. In: Tendencje i problemy techniki leśnej w warunkach leśnictwa wielofunkcyjnego. UP Poznań, 26-36 [in Polish].

WPŁYW GEOMETRII OSTRZA ŻŁOBIKOWEJ PIŁY ŁAŃCUCHOWEJ NA POZIOM WIBRACJI PILARKI SPALINOWEJ

Streszczenie. Poziom wibracji mierzono podczas przerzynki dziewięciu okorowanych kłód sosnowych. W badaniach zastosowano pięć żłobikowych pił łańcuchowych z ogniwami tnącymi typu dłuto o podziałce 0,325”. Piły miały różne kąty nachylenia krawędzi tnącej ostrza poziomego: 20°, 25°, 30°, 35° i 40°. Przerzynkę kłód prowadził operator pilarki. Pomiary wykonano osobno na uchwycie kabłąkowym i sterowniczym w trzech osiach x, y, z. Dla każdego kąta wykonano na każdym uchwycie po 18 pomiarów. Zastosowano urządzenie pomiarowe Robotron M 1300. Zdecydowanie wyższe drgania odnotowano na uchwycie sterowniczym. Stwierdzono statystycznie istotne różnice w poziomie drgań mechanicznych podczas przerzynki piłą o różnych kątach. Korelacja między kątem a poziomem drgań miała charakter słabej zależności, ale tam, gdzie wystąpiła, była statystycznie istotna.

Słowa kluczowe: piła łańcuchowa, wibracje, geometria ostrza

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