Annals of Warsaw University of Life Sciences – SGGW
Agriculture No 66 (Agricultural and Forest Engineering) 2015: 89–98
(Ann. Warsaw Univ. of Life Sci. – SGGW, Agricult. 66, 2015)

The impact of initial tension on rapidity of dulling of saw cutting chains during cross-cutting of pine wood

ADAM MACIAK
Department of Agricultural and Forest Machinery, Warsaw University of Life Sciences – SGGW

Abstract: *The impact of initial tension on rapidity of dulling of saw cutting chains during cross--cutting of pine wood.* The article presents results of research, aimed at comparison of rapidity of dulling of saw cutting chains depending on the initial tension level. Research was conducted during cross-cutting of moist pine wood. Measurements were conducted for two states of tension of saw chain: loose and tense. Dulling was determined on a basis of measurement of radius of rounding of saw chain cutting edges. As a result of the study, it turned out that tension exerted significant impact on rapidity of dulling of saw chains. This phenomenon is more visible when working with loose saw chain. Tension decrease also leads to greater diversification of radius of rounding of cutting edges of individual saw chains.

Key words: petrol chainsaw, saw tension, dulling of blades, cutting efficiency

INTRODUCTION

A portable petrol chainsaw is a basic tool used in forestry in logging process. Despite substantial technical progress and various threats to operator during work with a chainsaw [Skarżyński and Lipiński 2013], this tool has not been replaced with heavy mobile machinery, such as strippers or harvesters. Its share in logging in PGL LP represents about 90% [Wójcik 2013]. Due to great popularity of chainsaws and sawing machines in forestry, not only empirical research, but also theoretical analyses on effectiveness of their work have been conducted.

Analysis of chainsaw operation has been studied by Więsik [1994], who developed a graph of a model of the relational wood cutting model, allowing for analysis of impact of basic factors on performance and energy efficiency of wood cutting process. The graph served as a basis for mathematical models, developed by other authors [Górski 1996b, Maciak 2001]. Apart from such parameters as the chainsaw structure and blade geometry [Maciak 2000, Maciak and Gendek 2007] and feed force [Maciak 2004] on the cutting effects achieved, the saw chain initial tension is of great significance. This parameter depends on the sawing machine operator, who is able to adjust it. A change in initial tension of a saw chain results in change of the resistance of saw chain movement along the guide bar, as well as freedom of swing of chains during operation. Swing of a chain in the kerf plane exerts impact on cutting effects obtained [Maciak 2013].

During analysis of photographs of wood cutting made with a rapid camera, To et al. [1967] noticed that as initial tension increased, the angle of swing of chains during machine cutting is reduced. Botwin and Botwin [1979] found that a loose saw chain leads to decrease in the cutting efficiency. Excessive tension, on the other hand, results in substantial energy losses due to friction and faster wear and tear of cutting mechanism. Górski [1996b] stated that cutting efficiency in loose saw chain was 50% lower in comparison with a properly tensioned saw chain. Research conducted by Trzeciak [2003] confirmed that excessive tension of saw chain resulted in a visible decrease in the cutting efficiency. Maciak [2013] found that a decrease in initial tension of saw chain increased the freedom of swing of cutting chain in the kerf plane. This reduces the value of the blade penetration time coefficient, which is the ratio of real time of blade cutting to total cutting time. This results in deterioration of cutting efficiency of a machine and achieved cutting performance. During chainsaw operation, tension may change dynamically. This phenomenon is caused by non-uniform speed and angular acceleration of the crankshaft, particularly visible in the case of single-cylinder engines [Gendek 2006]. This results in high acceleration values of the chainsaw, resulting in substantial forces of inertia, which are often several times greater than the active cutting forces [Więsik 2007]. Apart from the factors listed above, substantial impact on the cutting effect is exerted by the cutting chain geometry. Among all of the geometric parameters, high impact on the effects of cutting is the angle of inclination of the cutting edge [Komorowski 1987, Stempski and Grodecki 1998], lowering and shape of the feed limiter [Górski 1996a] and dulling of the chainsaw blades [Bieńkowski 1993, Górski 1996b]. The authors agree that increase in the radius of the cutting edge results in deterioration of the cutting efficiency achieved.

The objective of the research presented was to determine the impact of reduction of initial chainsaw tension on the rapidity of dulling of the chipper type chainsaw during cross-cutting of pine wood.

MATERIAL AND METHODS

Research was conducted using pine wood in form of cut logs of diameter of 35 to 37 cm and of length of 120 cm. The average absolute moisture content in the wood was 79.2%. Moisture content was determined using the WPS 210S moisture analyzer, allowing for measurement with the accuracy of 0.02%. Wood hardness in the front face part was 14.07 MPa. Hardness of the wood examined was specified using Brinell method, on the facing surface, and the measurement accuracy was 1 MPa.

The measurements were conducted using a Husqvarna sawing machine, model 357XP. According to manufacturer data, the swept capacity of the machine is 56.3 cm^3, the power – 3.2 kW, and mass excluding the cutting mechanism, with empty containers – 5.5 kg. This sawing machine is a professional tool of medium capacity. The sawing machine was equipped with a guide bar 15 inches long. Research was conducted using a saw chain with chisel type blades. The tooth pitch was 3/8 inch, the angle of inclination of the horizontal cutting edges was 65°, lowering of the feed limiter was 0.5 mm. The saw chain had 28 cutters.

The research was conducted for two tension states of the chainsaw: tense and loose. It was assumed that the saw chain was tense, when after suspending in the middle of the guide bar of a weight of 20 N, its deflection – f (Fig. 1) was equal to 5 mm, and it was assumed to be loose when f = 8 mm.

During measurements, the wood was placed on a sawhorse at the height of 60 cm. In order to prevent its movement, it was fixed to a sawhorse with fixing tape. Freshly cut pine wood was used for measurements. Before measurements, saw chain had been sharpened. In order to get as close as possible to the real conditions, sawing machine was handled by an experienced operator, who attempted to maintain similar values of the feed force during cross-cutting. After 35 kerfs, a saw chain was sharpened and the initial tension was changed.

Rigid fixing of the sawing machine to the measurement workstation, allowing for maintaining of the constant feed force [Maciak 2013] would result in the sawing conditions being different from the real conditions. It could also lead to a different behavior of the cutting chain in the kerf. This would be caused by frequency of natural vibration being different in comparison with normal operation [Górski 2001]. During research, the following parameters were measured: kerf area, cutting time, radius of rounding of saw chain blades.

The kerf area was established on the basis of two mutually perpendicular diameters, measured using a section guide with accuracy up to 1 cm. For calculation of the kerf area, the average of two measurements was applied. Calculations were conducted using the disk area equation.

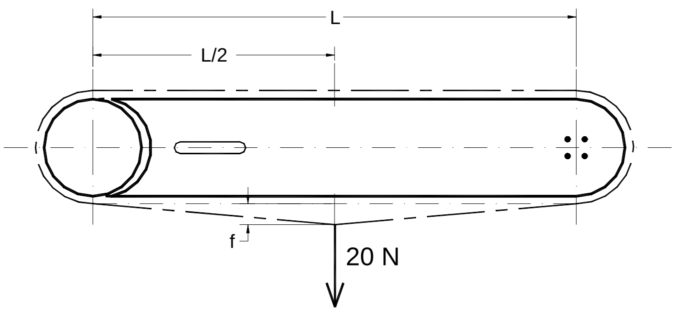

FIGURE 1. The mode of measurement of the saw chain tension

The cutting time was measured from the time of contact of the chainsaw with wood until the end of cutting. Time was measured using a Casio stopper with accuracy of 0.01 s.

The area efficiency of cutting was calculated on the basis of the following correlation [Maciak 1994]:

$$W = \frac{A}{t} \tag{1}$$

where:
W – area efficiency of cutting [cm^2/s];
A – kerf area [cm^2];
t – sawing time [s].

The edge rounding radius was measured every five kerfs and after each saw chain sharpening. The edge rounding radius after sharpening ranged from 7.9 to 8.75 μm.

The position for measurement of blade dulling consisted of a Nikon ALPHAPHOT – 2 microscope equipped with a halogen illuminator OH 1 for observation in reflected light with a mounted digital camera. In order to perform measurement, a blade was impressed in a lead plate, which was then placed on the table of the microscope. Using a magnification of 400×, the image obtained was recorded. Afterwards, using MultiScan Base v.18.03 software, analysis of the image was conducted and radius of rounding of blade cutting edge was measured (Fig. 2). The imprints

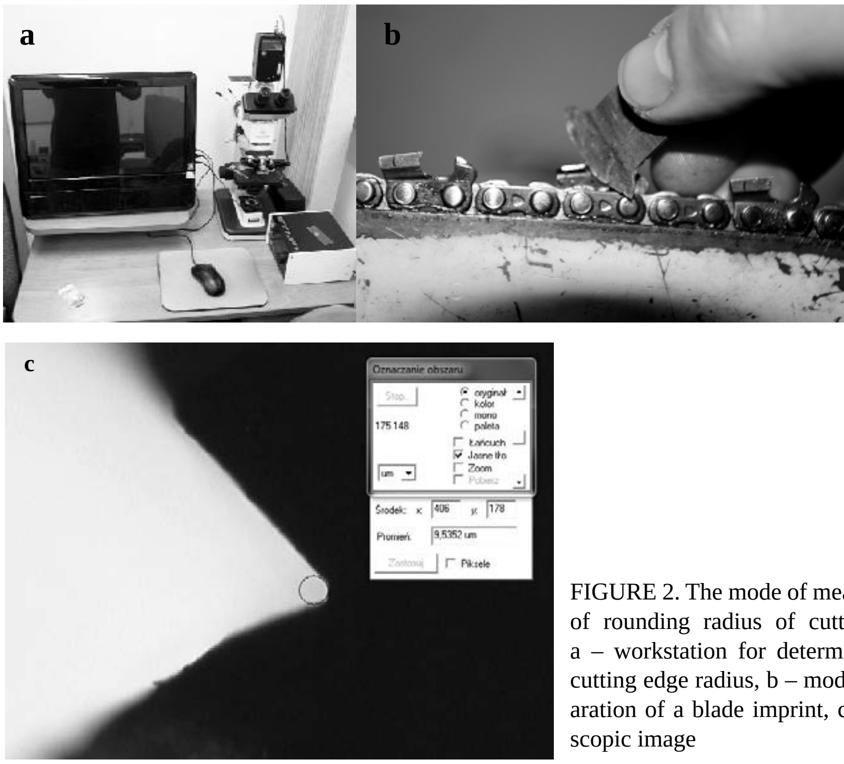

FIGURE 2. The mode of measurement of rounding radius of cutting edge: a – workstation for determination of cutting edge radius, b – mode of preparation of a blade imprint, c – microscopic image

were collected in the middle of length of horizontal cutting edge of each saw chain. In each case, 28 imprints were obtained, which corresponds with number of chain cutters of saw.

RESULTS

Tables 1 and 2 present the statistically processed results of measurements of the impact of the kerf area (A) on radius of rounding of cutting edge (ρ). The results obtained have been illustrated by Figure 3.

The regression straight lines, presented in Figure 3, can be described using the following equations:

- for a tense chain $\rho_n = 0.00017 \cdot A + 8.43$; $r = 0.91$;
- for a loose chain $\rho_1 = 0.00025 \cdot A + 8.45$; $r = 0.94$.

On the basis of the results obtained, it can be stated that average radius of rounding of cutting edge of tense chain increased by 6.05 μm (from 8.29 to 14.34 μm). When chain was loose, average radius increased by 8.79 μm (from 8.42 to 17.21 μm). The difference in increment of rounding radius of blade cutting edge between tense and loose chain was thus equal to 2.74 μm. For chains after sharpening, rounding radius of blade cutting edge of chains was within the

TABLE 1. Results of measurements of the impact of kerf surface on radius of rounding of cutting edge of tense chain blades

Kerf area [cm^2]	Average	Minimum	Maximum	*SD*
	μm			
0 (after sharpening)	8.29	7.95	8.74	0.41
5 087	9.21	8.74	9.92	0.48
10 174	10.1	9.54	11.12	0.61
15 260	10.91	10.10	11.85	0.70
20 347	12.09	10.74	13.34	0.81
25 434	12.69	11.33	14.12	1.10
30 521	13.13	11.64	14.81	1.23
35 608	14.34	12.71	15.89	1.35

TABLE 2. Results of measurements of the impact of kerf surface on radius of rounding of cutting edge of loose chain blades

Kerf area [cm^2]	Average	Minimum	Maximum	*SD*
	μm			
0 (after sharpening)	8.42	7.90	8.75	0.38
5 065	9.86	9.23	10.74	0.49
10 171	11.12	10.09	11.81	0.72
15 156	11.86	10.53	12.80	0.95
20 242	13.35	11.92	15.09	1.26
25 307	14.67	13.51	16.82	1.38
30 373	16.07	14.31	17.92	1.49
35 438	17.21	15.50	19.68	1.74

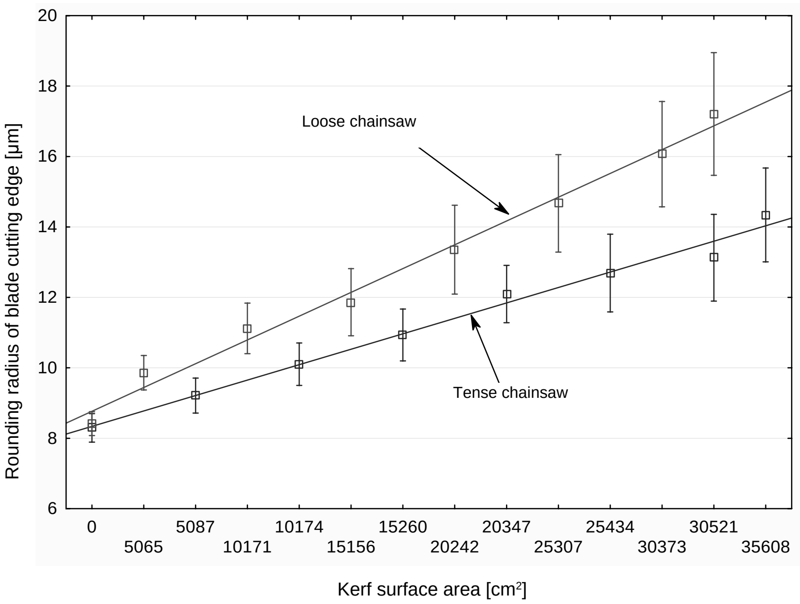

FIGURE 3. Correlation between radius of rounding of cutting edge of a chainsaw blades and the kerf area

range of 7.95–8.74 and 7.9–8.75 µm, standard deviation of radius of rounding of blade cutting edge was 0.41 and 0.38 µm, respectively. During work, the difference in the degree of dulling between individual chains increased. After 35 kerfs, radius of rounding of blade cutting edge of tense chain was within 12.71 to 15.89 µm, and standard deviation of this parameter was 1.35 µm. In the case of loose chain, radius of rounding of blade cutting edge was within the range of 15.5–19.68 µm, while standard deviation was equal to 1.74 µm. It can be suspected that the reason for faster dulling of blades of loose chain and greater diversity in the degree of dulling of individual chains is a greater ability of swinging of chains in kerf in comparison with tense saw chain [To et al. 1967, Maciak 2013]. Increased freedom of swing in the kerf plane may result in a less stable operation of loose saw chains.

It turned out that increase in radius of rounding of blade cutting edge takes place more quickly in the case of loose saw chain. Along with increase in the kerf area, differences in radius of rounding of blade cutting edge between individual saw chains also increases. This diversification is also influenced by decrease in saw chain tension. The blades of loose saw chain get dull faster in comparison with a saw chain, which has been tensioned in accordance with the user manual. Moreover, in the case of loose saw chain, there are greater differences in dulling of individual chains in comparison with tense saw chain. Statistical analysis has shown that in all cases, the kerf area exerts significant impact on dulling of blades.

In both cases, the change in rounding radius can be described using a straight line. It can be assumed that dry friction takes place between saw chain blades and the wood. According to available literature on the subject [Gawlik 1988], the typical course of wear and tear of friction surfaces, under the conditions of dry friction, is presented by Lorenz curve. The course consists of three typical periods: preliminary dulling, normal dulling, end dulling. In the first period, grinding-in of the friction surfaces takes place. In the case of cutting, the micro-irregularities of the surface are levelled. The degree of wear and tear depends mostly on the degree of finishing of the blade surface and – to some extent – on its geometry. The second stage is characterized by constant war and tear intensity, which depends on the working conditions. During the third stage, the intensity of wear and tear increases more rapidly, leading to complete loss of ability to cut by the blade. It is due to reaching of specific wear and tear parameters and a change in the established conditions of operation.

The characteristics of wear and tear of blades, obtained during measurements, corresponds with the first period of wear and tear, described by Lorenz curve, which is equivalent to the grinding-in period. It can also be suspected that in the case of further work without sharpening, increasing radius of rounding of blade cutting edge would slow down.

Impact of the kerf area on the cutting efficiency is presented by Figure 4. The correlations between cutting efficiency and kerf area (A) can be presented with reference to the following regression equations:

- tense saw chain: $W_n = -0.00035 \cdot A + 73.43$; $r = 0.78$;
- loose saw chain: $W_l = -0.00062 \cdot A + 64.24$; $r = 0,91$.

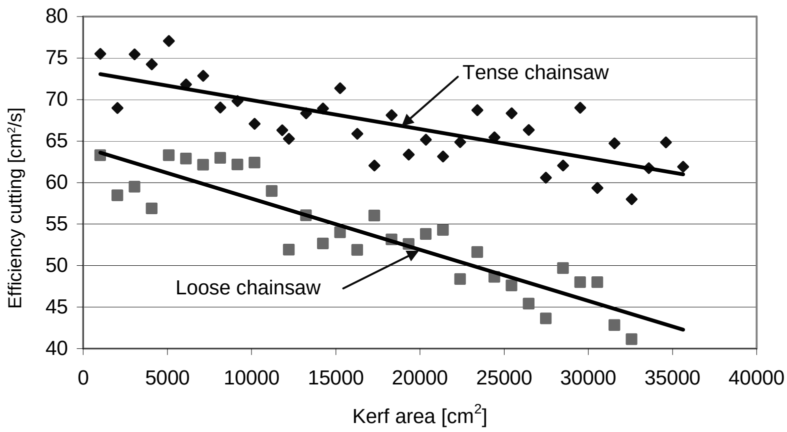

FIGURE 4. Correlation between cutting efficiency and increasing kerf area for the examined initial tension value of a saw chain

It can be stated that throughout the entire examined range, tense saw chain achieved higher values of the surface cutting efficiency in comparison with loose saw chain. This is consistent with the findings of other researchers [Bieńkowski 1993, Górski 1996b, Trzeciak 2003] and the earlier findings of the author [Maciak 2001]. A decrease in the value of the efficiency of surface cutting can be explained by an increase in radius of rounding of blade cutting edges. Other researchers [Bieńkowski 1993, Górski 1996b] have also confirmed the impact of increase in radius of rounding of blade cutting edges on deterioration of the cutting efficiency achieved.

It can be noted that the difference in the efficiency of surface cutting between loose and tense saw chain increased along with the kerf area. During dulling, efficiency of loose chain deteriorated more rapidly. This was caused by radius of rounding of blade cutting edges of saw chain increasing faster in comparison with tense saw chain. After 35 kerfs, efficiency of tense saw chain dropped by 16.5%, and efficiency of loose chain – by as much as 33.6%.

Figure 5 presents a comparison of the average values of cutting efficiency for individual cases examined, obtained throughout the entire saw dulling period. Statistical analysis has shown that there are significant differences between the values obtained. The average value of the surface cutting efficiency, obtained for tense saw chain, amounted to 66.18 cm^2/s. When cutting with loose saw chain, the average efficiency achieved amounted

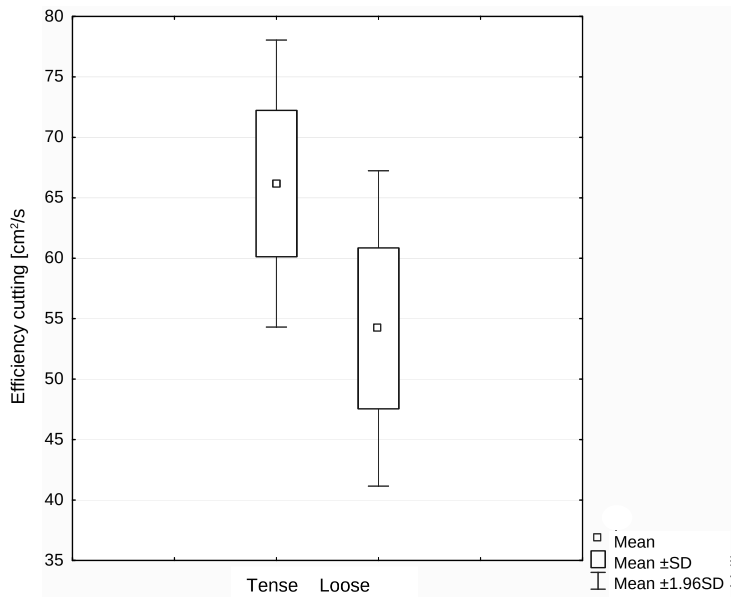

FIGURE 5. Comparison of the area cutting efficiency for loose and tense saw chain

to 54.19 cm^2/s. The difference in the average cutting efficiency between loose and tense saw chain amounted to 11.99 cm^2/s. Spreading of the values obtained was similar in both cases, as the standard deviation values obtained were rather close. For tense saw chain, the standard deviation value was 6.06 cm^2/s, while for loose saw chain it reached level of 6.65 cm^2/s.

SUMMARY AND CONCLUSIONS

- The average radius of rounding of blade cutting edge of tense saw chain after 35 kerfs amounted to 14.34 µm, while for the loose saw chain it amounted to 17.21 µm. During measurements, the average value of rounding radius of blade cutting edge of tense saw chain increased by 6.05 µm, and for the loose saw it was 8.79 µm.
- After 35 kerfs, efficiency of the tense saw chain dropped by 16.5%, while efficiency of the tense saw chain decreased by 33.6%.
- The average efficiency achieved by the tense saw chain amounted to 66.18 cm^2/s, while in the case of loose saw chain, it was 54.19 cm^2/s. The difference in the average efficiency value between tense and loose saw chain was 11.99 cm^2/s.
- Initial tension of saw chain exerts significant impact on the rapidity of dulling of blades and on the efficiency of surface cutting achieved.
- Cutting of wood with an appropriately tensioned saw chain results in less rapid dulling of the edges and allows for obtaining of a higher efficiency of surface cutting.
- Along with the number of kerfs performed, variability of radius of rounding of blade cutting edges increases between individual chains of a chainsaw. Variability of radius of rounding of blade cutting edge of individual chains is greater for loose saw chain.

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Streszczenie: *Wpływ napięcia wstępnego na szybkość stępiania się ogniw piły podczas przerzynki drewna sosnowego.* W artykule przedstawiono wyniki badań nad wpływem napięcia wstępnego piły na szybkość tępienia ostrzy jej ogniw tnących. Badania przeprowadzono podczas przerzynki drewna sosnowego. Badane drewno było wilgotne. Pomiary przeprowadzono w dwóch stanach napięcia piły: napiętym i luźnym. Stępienie określano poprzez pomiar promienia zaokrąglenia krawędzi tnącej ogniw piły. W wyniku badań okazało się, że napięcie istotnie wpływa na szybkość tępienia się ostrzy piły. Zjawisko to zachodzi bardziej intensywnie w przypadku pracy piłą z luźnym łańcuchem. Spadek napięcia powoduje też większe zróżnicowanie promienia zaokrąglenia krawędzi tnących poszczególnych ogniw piły. W trakcie pomiarów przyrost średniego promienia zaokrąglenia krawędzi tnącej piły z napiętym łańcuchem wyniósł 6,05 μm, a z luźnym – 8,79 μm. Średnia wydajność osiągnięta przez piłę z napiętym łańcuchem wynosiła 66,18 cm^2/s, a piłą luźnym łańcuchem – 54,19 cm^2/s. Różnica w wartości średniej wydajności skrawania między napiętym a luźnym łańcuchem wynosiła 11,99 cm^2/s.

MS received May 2015

Adam Maciak
Wydział Inżynierii Produkcji SGGW
Katedra Maszyn Rolniczych i Leśnych
02-787 Warszawa, ul. Nowoursynowska 164
Poland
e-mail: adam_maciak @sggw.pl