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Impact of the feed force on discontinuity of wood cutting with petrol chainsaw

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Abstract: *Impact of the feed force on discontinuity of wood cutting with petrol chainsaw.* The article presents results of the research on the impact of the feed force on discontinuity of the process of wood cutting with petrol chipper type saw. Analysis of discontinuity was conducted on basis of analysis of variability of instantaneous values of the feed force. Pine wood was used for research purposes. It was found that the wood cutting process was discontinuous process. At times none of the chains performs the wood cutting function. The share of pauses in cutting depends on the feed force applied.

Key words: chainsaw, wood cutting, cutting strength, feed force

INTRODUCTION

To drive chainsaws, it is possible to use various types of engines: combustion, electrical, hydraulic or pneumatic engines. Most often, chainsaws are driven with single-cylinder, two-stroke combustion engines. Electrical drive is more often used for industrial purposes and for do-it-yourself tasks. On the other hand, hydraulic drives are usually mounted e.g. in harvester heads. Despite the substantial technical progress and threats associated with use of combustion sawing machines [Skarżyński and Lipiński 2013], it has not been driven out of the market by heavy mobile machines, such as cutters or harvesters. It is estimated that its share in logging in PGL LP amounts to about 90% [Wójcik 2014]. One of the main causes of such great share of sawing machines is the high price of purchase of the high-capacity machines. This results in the necessity of providing them with an appropriate scope of works, making it possible to maintain the acquisition costs at the level comparable with those obtained by a sawing machine [Nurek 2013]. In Poland, it is often rather difficult to achieve.

A combustion engine, particularly a single cylinder one, is characterized by variable piston movement speed during a work cycle. It accelerates upon ignition of the mixture in the combustion chamber in order to slow down during the compression cycle. This results in discontinuity of speed and angular acceleration of the crankshaft [Gendek 2005]. This translates to high values of acceleration of the chainsaw, resulting in substantial inertia forces, which are often several times greater than the active cutting forces [Więsik 2007]. This feature distinguishes clearly the process of cutting wood with a chainsaw driven by a combustion engine from the process of cutting with the same chainsaw, driven by an electric or a hydraulic engine. Another factor, which may influence discontinuity in chainsaw operation, is its structure. Individual chainsaw components are characterized by freedom of rotation in relation to their longitudinal axes. This results in a situation, in which the saw chains can freely move in the kerf lane, depending on the cutting conditions [To Doi et al. 1967]. This feature distinguishes chainsaws from other saws, such as circular and band saws, in which the edges are not able to change their mutual positioning. Behavior of the chainsaw in the kerf may depart from behavior of elementary blades (wedges) or other types of saws, for instance, frame saws, in which the mutual positioning of the blades is fixed. Many researchers have dealt with impact of various factors on cutting performance, as well as impact of sawing machines on humans and their environment, Sowa [1989] including Stempski and Grodecki [1998], Wojtkowiak [2004]. On the other hand, literature says little about behaviors of chainsaws in kerfs and the course of the wood cutting process using such saws.

According to the classification, the cutting process can be divided into continuous and discontinuous [Kaczmarek 1970]. Discontinuous cutting means that the cutting blades periodically sink into the material being cut and are removed from it. Researchers dealing with this issue assumed that if the kerf height is greater than the saw pitch, the cutting process is continuous and every cutting chain cuts continuous chips [Koczegorow 1970, Douda 1973, Maciak and Gendek 2007]. Obliwin et al. [1988] stated that the factors that influence the dynamics of changes in the cutting resistance include: angular velocity, number of the driving wheels of saw and saw mass. Some researchers state that high variability of the cutting strength is due to the fact that the blades cut through individual rings [Bierszadski 1958; Iwanowski and Wasilewskaja 1972, Lichniak 1981, Maciak 2004, Maciak 2004].

Reynolds and Soedel [1976] developed a dynamic model of the operator–sawing machine system, which was then used to analyze the forced vibration of the combustion engine sawing machine due to unbalance of the sawing machine engine crankshaft. Using this model, Górski [2001] stated that the cause of variability of the instantaneous cutting strength while operating an electric sawing machine is the change in thickness of the cut layer as a result of the sawing machine vibrations. Górski, examining the process of cutting using an electric saw, stated that the assumption of continuity of cutting is true only for small kerf heights up to 40 mm. He noticed that as the kerf height changes, dynamic phenomena occur, which interfere with the cutting process. This author was of opinion that cutting discontinuity was caused by self-excited vibrations of the electrical saw. He also determined the cause of these problems – unfavorable positioning of the main axes of rigidity of the mass-elastic-attenuating system, created by the operator holding the sawing machine. The frequency of this vibration is within the range of frequency of own vibration of the upper limbs of the operator. However, research on discontinuity of cutting under the conditions, in which the saw is held by the operator, may bring varying results, depending on the operator, their work position and level of tiredness. In his model, Coerman replaced the human operator with a system of masses, connected by springs and attenuators. The system is characterized by many degrees of freedom and many frequencies of own vibrations [Engel 2001]. The man–machine system is characterized by a complex dynamic structure and it is a non-linear, stochastic, discontinuous system, containing parameters that change over time. All researchers agree [Engel 2001, Cieślikowski 2007] that the frequency of own vibrations in the operator–sawing machine system depends on individual physical needs of the operator, their work station, tiredness etc. Therefore, in order to eliminate a variable factor, that is, the dynamic characteristics of the operator – sawing machine system, the sawing machine should be fixed to a work station with known parameters.

Gendek [2005] showed consistency of the frequency of changes in cutting resistance when using a combustion engine sawing machine with the engine work cycle. He found that the inertia forces resulting from the engine cycle result in a temporary shift in its tension, and thus – positioning of the cutting teeth in relation to wood and differentiation of the instantaneous cutting forces. A significant parameter during cutting of wood is the feed force, applied by the operator. All researchers agree that this value determines greatly the cutting performance achieved. Its increase results in increase in the level of performance obtained. Więsik [1990] stated that the maximum feed force should not exceed the value appropriate to attain the chip thickness defined by the feed limiter. Stronger feed forces result in a rapid increase in energy losses during the wood cutting process. Maciak [2001] has confirmed the occurrence of the optimum feed force value – after it is exceeded, cutting performance deteriorates. Its value varies depending on the sawing machine type. Analyzing the findings of various researchers [Sztyber 1963, Ciesielczuk 1973, Górski 1996b, Maciak 2001, Gendek 2005] it can be said that in the case of combustion engine sawing machines, the feed force value is decisive for the engine rotational speed, since the cutting force, as well as the sawing machine engine load change as the feed force changes, which results in an appropriate change in the engine rotational speed, depending on its working characteristics.

The objective of this study was to determine the impact of feed force on discontinuity of woodcutting by a chainsaw powered by a petrol engine.

MATERIAL AND METHODS

The study was conducted using pine wood of absolute moisture content of 9.7–12.9%. Moisture content in the samples was determined using a moisture analyzer WPS 210S, allowing for moisture content measurement with the accuracy of 0.01. Hardness of the wood examined, determined using Brinell method, on the facing surface, ranged from 31.5 to 36.8 MPa.

The cross-section of samples used for examination of cutting effects was rectangular, their width being 24 cm and kerf height – 14 cm.

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. It was used with a chainsaw with chisel type blades, marked in the catalogue of Oregon company as Super 70, with the tooth pitch of 3/8 inch, the guide link width was 1.5 mm and lowering of the feed limiter was 0.5 mm. The saw chain had 56 guide links and 28 cutters. During the tests, saw chain was tense. It was assumed that saw chain was tense, when after suspending in the middle of the guide bar of a weight of 20 N, its deflection (Fig. 1) was f = 5 mm.

During the test, the sawing machine was immobilized on the test bench. The bench is presented in Figure 1. The wood to be cut was put in a vise, horizontal

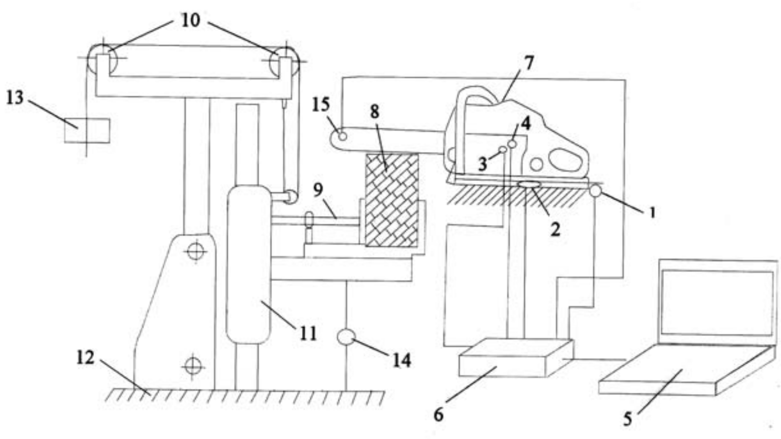

FIGURE 1. Diagram of stand for measurements on wood cutting: 1 – gauge for cutting force measurements, 2 – gauge for dynamic feed force measurements, 3 – gauge for engine crankshaft rotational speed measurements, 4 – gauge for clutch drum rotational speed measurements, 5 – computer, 6 – amplifier, 7 – chain saw, 8 – wood, 9 – vise, 10 – guiding rollers (directional), 11 – slide, 12 – base, 13 – weight, 14 – detachable gauge for static feed force measurements, 15 – gauge for guide temperature measurements

to the sawing machine. Vertical movement of wood was possible thanks to the appropriate weights, acting on the vise through a steel rope, attached to guide rollers. Obtaining of varied feed force values was possible thanks to modification of the weight mass. Data was saved on the hard disk using ESAM 3 software. Recording of measurement data took place at the frequency of 60,000 measurements per second. The same software allowed for analysis of measurement data later on.

The chainsaw cutters moved in the vertical plane – the horizontal blade of the cutter performed perpendicular cutting movement. After each kerf, the sawing machine was turned off in order to prepare the wood for the next trial. During the test, the following parameters of the cutting process were measured: feed force, cutting force, rotational speed of the engine shaft, rotational speed of clutch cup.

Accuracy of measurement of individual parameters was as follows:

- rotational speed ±1 rpm;
- feed force – P_p ±5% (measured using a dynamometer prior to commencement of cutting);
- cutting, force – P_s ±8%.

Each time, prior to commencement of measurement, the feed force value was determined using weights. Measurements were conducted in series. During each series, the feed force was increased gradually. Each series consisted of 12 measurements. Before each series of measurements, the entire system was graduated, and before each individual measurement, it was reset to zero. Three series of measurements were conducted for each set of conditions. In order to ensure the proper accuracy of measurements, the measurement system was launched half an hour prior to commencement of the measurement procedure in order to stabilize the temperature of the electronic components and their parameters. If a knot was noticed on the cross-section during measurement, the results of such measurement were discarded, and the test was repeated on a knotless surface.

During the test, dulling of the chainsaw was controlled through measurement of radius of rounding of blade cutting edge (ρ). The blade edge rounding was measured every five kerfs and after every sharpening of the chainsaw. The average radius of rounding of the chainsaw blades during the tests amounted to 8 to 12 μm. This is sufficient to state that a saw chain was sharp.

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 the measurement, the 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 the radius of rounding of the cutting edge was measured.

For analysis of continuity of cutting, the cutting force curve was examined to select a fragment, in which the average cutting force stabilized, determining the time, at which the temporary value of the cutting force was greater than 0 N, that is, the real time, in which the cutting blades performed the cutting function. This allowed for measurement of the blade penetration time coefficient, which is the ratio of the sum of the real times of blade penetration of the kerf bottom to the total time of performance of a given kerf surface, described by the following equation:

$$\tau = \frac{1}{T_o} \cdot \sum_{i=1}^{n_c} t_{ei} \qquad (1)$$

Where:
τ – blade penetration time coefficient;
T_o – time of performance of a given kerf area [s];
n_c – the number of cutter penetrations of kerf bottom over time (T_o);
t_{ei} – time of chip cutting by chainsaw cutters during single penetration of kerf bottom [s].

RESULTS

Figure 2 presents a fragment of the cutting force record at time length of 0.036 s. As it can be seen, the cutting process is not continuous, but intermittent. In some fragments, the cutting force drops to 0 N – no cutting takes place. Afterwards, a rapid increase in the cutting force is recorded, which suddenly drops to 0 N once again.

Changeability of the temporary cutting forces is very high, for instance, the

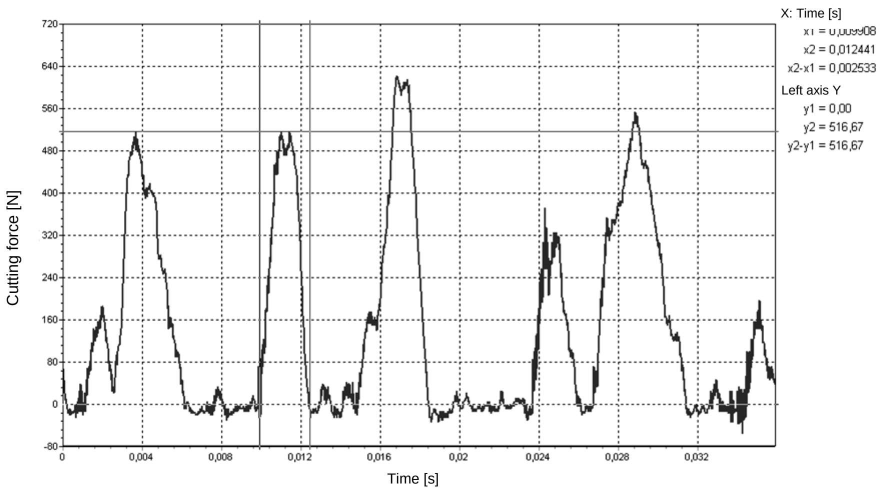

FIGURE 2. A fragment of the cutting force record of time length of 0.036 s: t_i – duration of the single immersion of saw chain cutters into the wood

time of duration of the period marked as (t_{ei}) from the moment, when the force starts to increase, until it drops to once again, is 0.0025 s. It can be assumed that this is the time, during which the chainsaw cutters in the kerf perform the cutting operation. During the time of 0.0013 s, the cutting force increases from 0 N to the value of 516 N. Time length t_{ei} corresponds with the cutting time length. Afterwards, the cutters are removed, which results in stopping of the cutting process for 0.0024 s – idle movement of the cutters takes place. In the case under consideration, the time of cutting is similar to the idle movement time of the chainsaw.

When the cutting force value drops to 0 N, it can be said that during this time, no cutter is cutting wood. On this basis, it is possible to conclude that all cutters in the kerf are penetrating the wood at the same time, after a certain chip thickness – h_1 (Fig. 3) has been attained, they move up; it is a cyclical process.

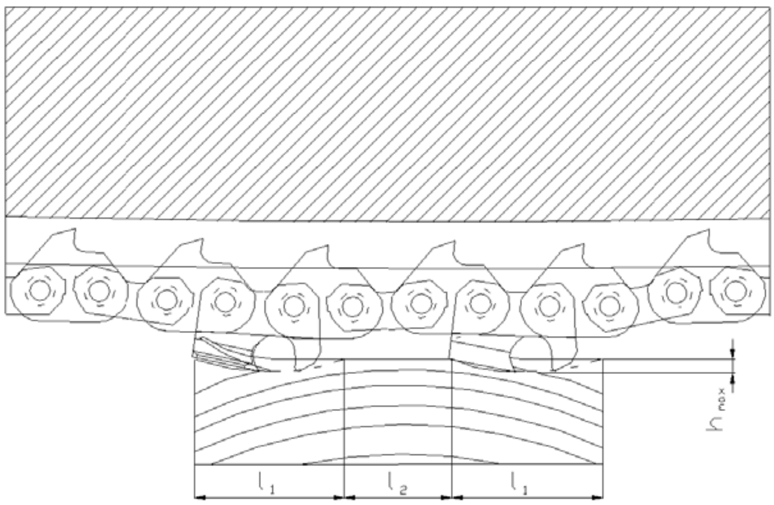

FIGURE 3. The course of the process of wood cutting with a saw chain: h_{max} – maximum chip thickness, l_1 – distance covered by cutter inside the wood, l_2 – distance covered by cutter outside the wood

Figure 4 presents variability of the cutting force with a relatively small feed force, amounting to 51 N. The rotational speed of the engine in this case is high. For the fragment illustrated by Figure 4, it is 12,240 to 12,320 rpm. The value of the blade penetration time coefficient $\tau = 0.29$. The average duration of a single blade penetration is 0.0027 s. Figure 5 presents the course of variability of the cutting force at a higher feed force of a single blade penetration is 0.0027 s. Figure 5 presents the course of variability of the cutting force at a higher feed force, amounting to 81 N. In this case,

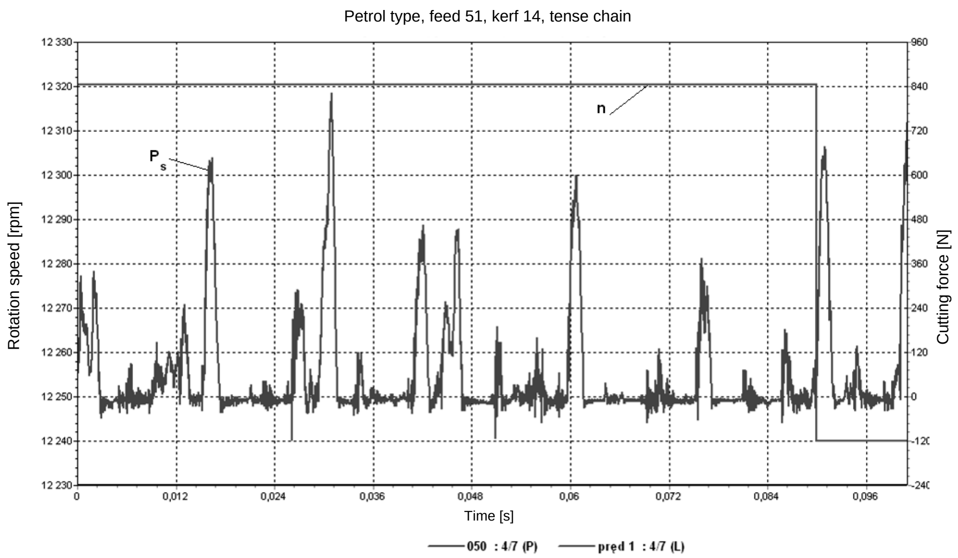

FIGURE 4. Variability of the cutting force at the feeding force of 51 N

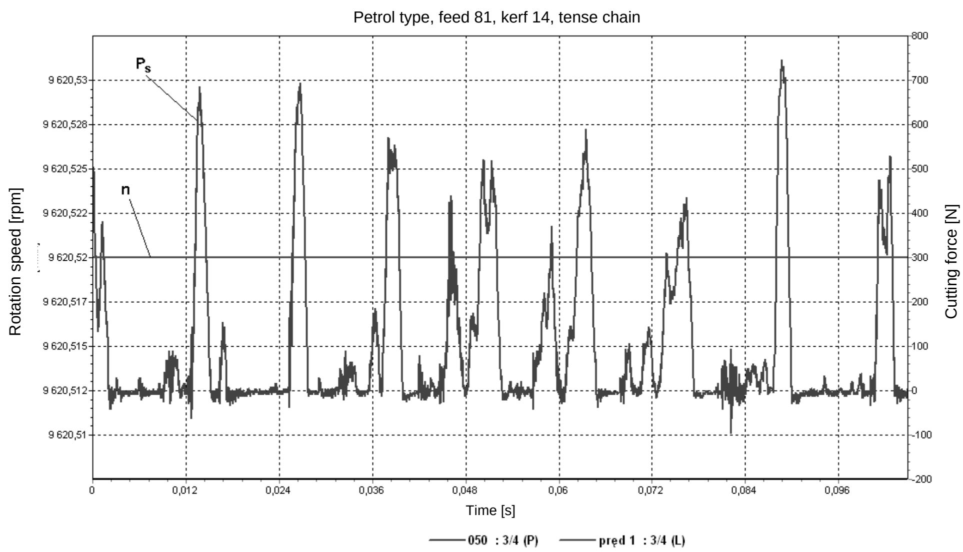

FIGURE 5. Variability of the cutting force at the feeding force of 81 N

rotational speed of the engine is 9,620 rpm. The speed decline resulted in increase of the blade penetration time coefficient to 0.47. It can be noted that the average duration of a single blade penetration time also increased, amounting to 0.0031 s.

Figure 6 presents the course of variability of the cutting force at the rate of feed amounting to 89 N. In this case, the

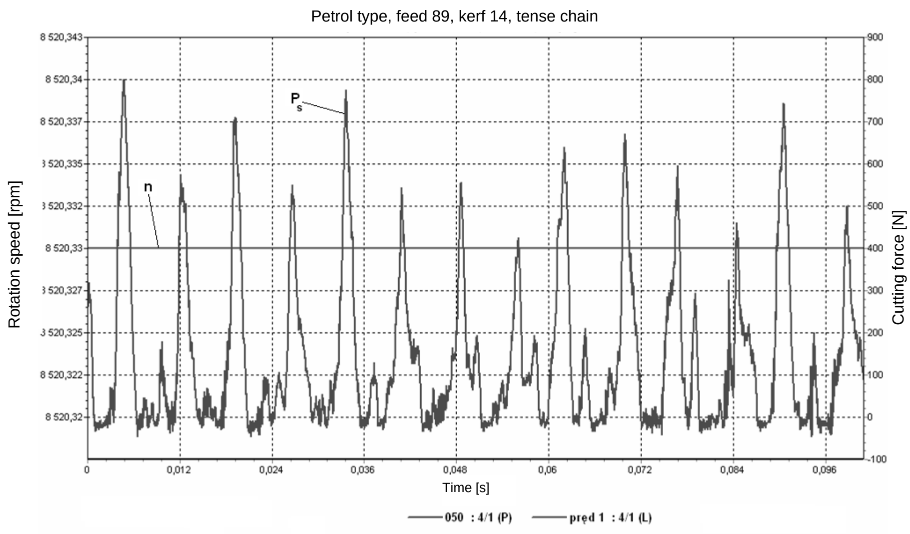

FIGURE 6. Variability of the cutting force at the feeding force of 89 N

engine speed is 8,520 rpm. The share of cutting time in overall working time has increased. In this case, the value of the blade penetration time coefficient amounts to 0.63. Average duration of a single penetration has also increased; in this case, it amounts to 0.0036 s.

Figure 7 presents the variability of the cutting force at the feeding force amounting to 118 N. The rotational speed in the presented fragment ranges from 6,240 to 6,320 rpm. It can be noted that breaks in the cutting process are very short, while

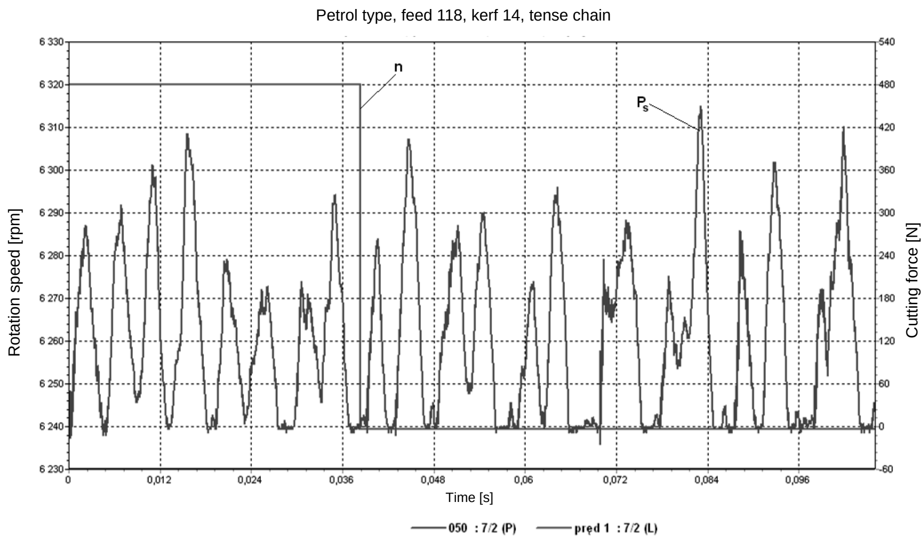

FIGURE 7. Variability of the cutting force at the feeding force of 118 N

the cutting time is long. In this case, the cutting time is 0.0788 s. It means that the blade penetration time coefficient is 0.79. The average single penetration time is 0.0062 s.

Figure 8 presents the impact of the feeding force value on the blade penetration time coefficient. Its value in tiveness of the cutting process. The increase in cutting efficiency, observed by other researchers [Ciesielczuk 1973, Bieńkowski 1993, Górski 1996b], can be explained by decreasing of discontinuity of cutting, that is, increasing of the share of the real cutting time in the overall wood sawing time.

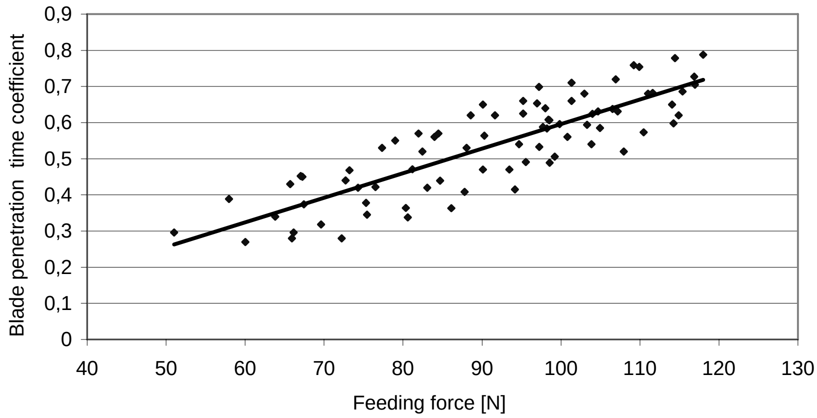

FIGURE 8. Influence of the feeding force on the blade immersion time coefficient

the study conducted ranged from 0.29 at the feeding force of 51 N to 0.79 at the feeding force of 118 N. This means that the share of the real cutting time in the total sawing time, in the best case, amounted to 79%.

Statistical analysis has shown that the value of the blade penetration time coefficient increases along a straight line along with the increase of the feed force applied. The trend line, presented in Figure 8, can be described by the following function: $\tau = 0.0068 \cdot Pp - 0.0838$.

The phenomenon of discontinuity of cutting probably influences the effec-

SUMMARY AND CONCLUSIONS

- In all of the examined cases, the wood cutting process was discontinuous.
- The share of the real cutting time in the overall sawing time during the study ranged from 29 to 79%. Its value increased along with the value of the feed force applied.
- The phenomenon of decline in cutting discontinuity can be used to explain the increase in cutting effectiveness, accompanying increase in the feed force, observed by other researchers.

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Streszczenie: *Wpływ siły posuwu na nieciągłość procesu skrawania drewna piłą łańcuchową napędzaną silnikiem spalinowym.* W artykule przedstawiono wyniki badań wpływu siły posuwu na nieciągłość procesu skrawania piłą łańcuchową żłobikową napędzaną silnikiem spalinowym. Analizy nieciągłości dokonywano na podstawie analizy zmienności chwilowych wartości siły posuwu. Badania przeprowadzono, wykorzystując drewno sosnowe. Stwierdzono występowanie okresów, gdy wartość siły skrawania wynosi zero. Świadczy to o występowaniu przerw w procesie skrawania, czyli proces skrawania drewna jest procesem przerywanym. Udział przerw w skrawaniu zależy od zastosowanej siły posuwu. Udział rzeczywistego czasu skrawania w całkowitym czasie piłowania w trakcie opisywanych badań wynosił od 29 do 79%. Jego wartość była tym większa, im większa była wartość przyłożonej siły posuwu.

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