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MACHINES FOR PRIMARY LOG CUTTING: PART I – A STUDY ON SOME OPERATIONAL INDICATORS

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ABSTRACT

The paper presents experimental results obtained during the processing of logs with different machines for primary cutting of logs – a vertical band saw machine with a carriage feed mechanism (*Üstünkarli* – Turkey), a circular saw machine for logs (*Kallion Konepaja Oy* – Finland) and a mobile horizontal band saw machine (*Arsov 90 Ltd.* – Bulgaria). The places for conducting the research are the manufacturing conditions of Training and Experimental Forest Range "G. Avramov" – the village of Yundola, Training and Experimental Forest Range "Petrohan" – the village of Burzia and "Petnop" Ltd. – the town of Varshets. The influence of basic parameters related to processing with these machines – feed speed and cutting amount, on the quality of the obtained wood materials was determined. The evaluation metrics measured are dimensional accuracy and surface roughness. The productivity of the machines was also determined. The studied wood species was Scots pine (*Pinus sylvestris L.*). The obtained results were analyzed and practical recommendations were proposed.

Key words: log cutting machines, Scots pine, productivity, roughness, work accuracy.

INTRODUCTION

The quality of the surfaces obtained after processing is an important indicator that characterizes the work process of industrial equipment, which also includes woodworking machines. Various parameters are found in the literature that are used to characterize it. According to some authors, the quality of surfaces is equivalent to their roughness. However, other authors indicate that it also includes the accuracy of the dimensions of the materials obtained, as well as the straightness of the cut (Ivanovsky *et al.* 1972, Bershadsky and Tsvetkova 1975, Gochev 2005).

The feed speed is one of the main parameters of the milling process. To a significant extent, the productivity of the machine depends on it. The above-mentioned machines work on the closed method of cutting, in which this parameter is limited by the power of the engine driving the cutting mechanism, the required class of roughness and the working capacity of the blade gullet. In previous studies related to the cutting power of band saw machines, it was found that, for the most part, their motors remained unloaded (Atanasov 2013, Atanasov 2014). On the other hand, there are a number of studies related to the roughness and dimensional accuracy, which is directly connected to the stability of the cutting tool and, hence to the workability of the gullet in band saw machines (Atanasov *et al*. 2018, Atanasov 2015). Papers related to logs as a material can be easily found as well – quantitative yield, log shape and size, defects and sorting (Taube *et al.* 2020, Koynov 2019, Trichkov and Koynov 2018). However, there is not a large number of studies regarding productivity, dimensional accuracy and roughness with log cutting machines, as well as a comparison between their different types (Atanasov 2021). This also determines the aim of the present study – to determine the influence of the main parameters of the cutting process on the roughness of the obtained surfaces, the accuracy of the dimensions and the productivity when cutting logs with the most widespread machines in our country – a circular saw machine, vertical band saw machine with carriage feeding, and horizontal band saw machine with manual feeding. The current paper is one part of a larger study (Atanasov 2024).

METHODOLOGY

For conducting the experimental studies, a vertical band saw machine with a carriage feed (*Üstünkarli* – Turkey), a mobile horizontal band saw machine (*Arsov 90 Ltd.* – Bulgaria) and a circular saw machine for logs (*Kallion Konepaja Oy* – Finland) were used. The places for conducting the research are the manufacturing conditions of Training and Experimental Forest Range "G. Avramov" – the village of Yundola, Training and Experimental Forest Range "Petrohan" – the village of Burzia and "Petnop" Ltd. – the town of Varshets. Figure 1 presents the kinematic schemes of the cutting mechanisms of the machines, as well as some of their parameters. The linear and angular parameters of the cutting tools are presented in Table 1.

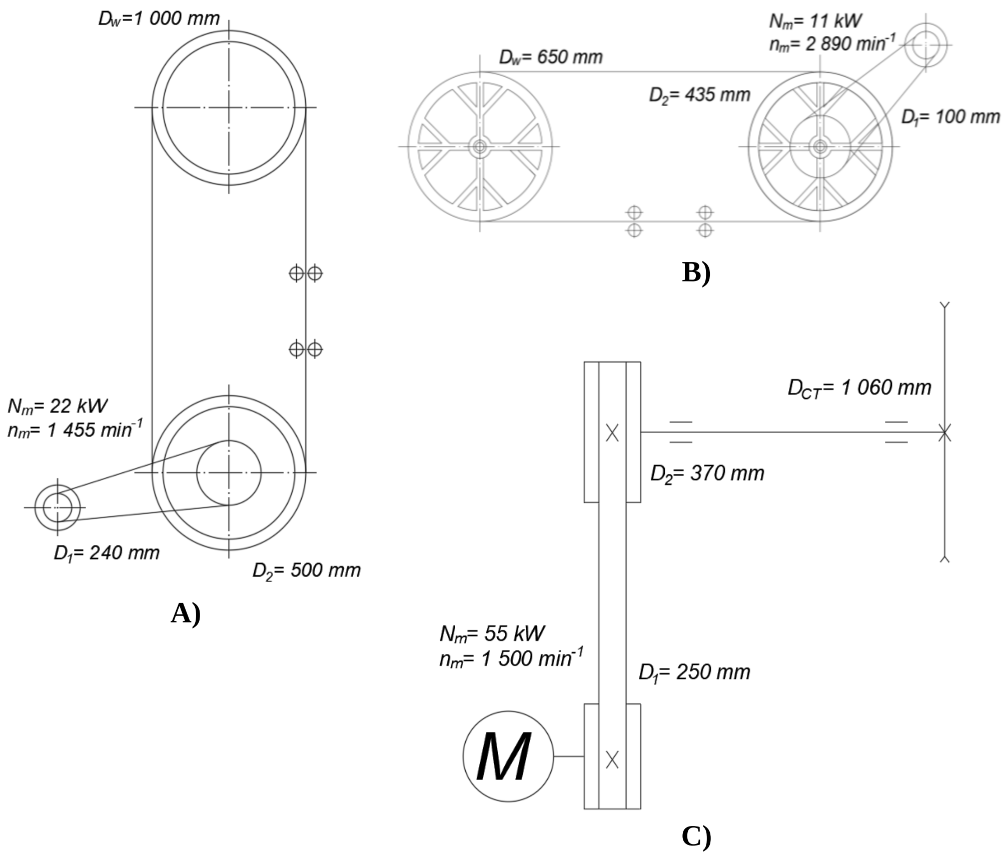

Figure 1: Kinematic schemes of the cutting mechanisms and some basic parameters of the studied machines (A – vertical band saw machine with a carriage feed mechanism, B – mobile horizontal band saw machine, B – circular saw machine for logs)

The test samples used for the experiment are logs of Scots pine, which were cut into boards with a thickness of 25-30 mm. Some of them can be seen in Figure 2.

The moisture content of the sawn wood was measured using a *Lignomat Tester* (Germany), and the density was determined by weight method using a *RADWAG WLC 1/A2* (Poland) electronic balance and tape measure. With the help of the device *MASTECH MS 6300* (China), the temperature and relative humidity of the air were also measured during the experimental studies, since, although to a significantly lesser extent, they can affect the final results.

The main factor whose influence on roughness and dimensional accuracy is determined is feed speed v_f. In addition, the amount of cut wood (Q_c) was also measured. Since the feed rate in all machines varies continuously, either by hydraulic mechanisms or by hand pushing, it is difficult to fix it accurately. For this reason, the average speed was measured according to the following formula

$$v_f = \frac{L_l}{t_c}, \tag{1}$$

where v_f is the average feed speed, m.min^{-1};

L_l – the length of the log, m;

t_c – the time to perform the relevant cut, min.

A tape measure and stopwatch were used. In addition, in order to make the results comparable, the range of variation of the feed speed was chosen to be approximately the same, although the circular machine and the band saw with carriage feeding mechanism allow a higher feed speed.

Table 1: Linear and angular parameters of the cutting tools of the machines under study

Parameters of the cutting tool of the vertical band saw machine *USTUNKARLI LTD**	
Manufacturer company	*CARL RÖNTGEN*
Angular parameters: rake angle/ sharpening angle γ/β [°]	18/62
Pitch t and height of the teeth h', width of stylized tip s' [mm]	40/12.1/2.2
Thickness and width of the blade B [mm]	1.1/119.2
Type of the teeth	Stellitized
Parameters of the cutting tool of the horizontal band saw machine *Arsov 90*	
Manufacturer company	*Arsov 90 Ltd.*
Angular parameters: rake angle/ clearance angle γ/α [°]	10/30
Pitch t and height of the teeth h', part-set size s' [mm]	22/5/0.60
Thickness and width of the blade B [mm]	1.14/50
Type of the teeth	Hardened
Parameters of the cutting tool of the circular saw machine *Kallion Konepaja Oy*	
Manufacturer company	*HW Kreissägeblätter*
Angular parameters: rake angle/ clearance angle γ/α [°]	25/15
Pitch t and height of the teeth h' [mm]	40/22
Thickness s, thickness of cutting hard alloy s' [mm]	4.1/5.4
Type of the teeth	Carbide

** When performing the experiments with the vertical band saw machine, 2 blades were used, and their average values of their main parameters are presented*

Figure 2: Received Scots pine boards

The amount of timber cut is defined in m², as this way the cutting pattern has no influence.

$$Q_c = L_l h_{av}, \quad (2)$$

where Q_c is the amount of timber cut, m²;

h_{av} – the average cutting height, m.

The average cutting height was measured with a tape measure in the middle of the board.

The cutting speed was also determined, since it also affects the parameters studied. For this purpose, the known dependence was used, also taking into account the slip ratio of the gear

$$v_c = \pi D n_m \frac{D_1}{D_2}(1 - \varepsilon), \quad (3)$$

where v_c is the cutting speed, m.s^{-1};

D – the diameter of the wheel (circular saw blade), m;

n_m – the revolution of the electric motor, s^{-1};

D_1 – the diameter of the drive belt pulley, m;

D_2 – the diameter of the driven pulley, m;

ε – the slip ratio of the gear.

To determine the roughness, the $\overline{R}m$ parameter was used, which is used in the primary cutting of logs. For this purpose, an indicator depth gauge with a measuring clock was used in accordance with the BDS 4622:86 standard. The measurement of the thicknesses of the parts was carried out with a caliper, and the arithmetic mean value of the absolute values of the differences with the predetermined dimensions of the boards was calculated. When calculating this parameter, the average value of the feed speed for the two cuts in which the corresponding board was obtained was taken into account. The results were compared with the BDS EN 1313-1:2010 standard, which refers to the permissible deviations in the dimensions of a board made of softwood species. There are a total of 20 measurement locations for the studied parameters and they are located symmetrically on both sides of the obtained wood materials. The distance between them a is determined depending on the length of the log. Schematically, the measurement points can be seen in Figure 3 (Atanasov 2014).

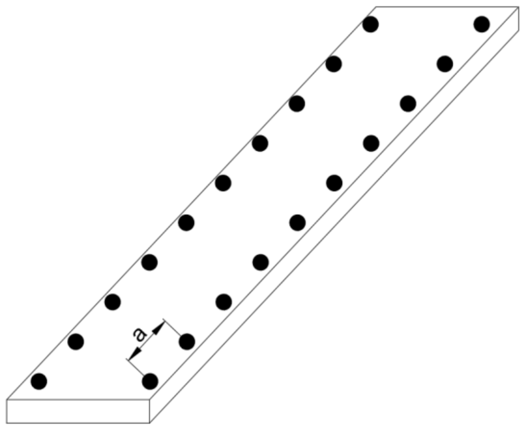

Figure 3: Measurement points of the studied parameters

Productivity is also defined in m^2, but in the case per minute, the operator performs the feed at a speed that is normal for the respective cutting height.

The following dependency was used

$$Q_m = v_f h_{av}, \tag{4}$$

where Q_m is the productivity of the machine, m^2.min^{-1}.

RESULTS AND DISCUSSION

The obtained cutting speeds for the examined machines, after calculation according to dependence 3, are: circular saw machine 56 m.s^{-1}, band saw with carriage feed 37 m.s^{-1} and horizontal band saw 23 m. s^{-1}. The results for the density and moisture content of the Scots pine wood used for the experimental studies, as well as the conditions for the experimental studies, are presented in Table 2. The volume of logs used in the "G. Avramov" is 8.2 m^3, "Petrohan" 4.9 m^3 and 4.2 m^3 in "Petnop" Ltd.

Table 2: Results for the density and moisture content of the wood and the conditions for conducting the experiments

Manufacturing workshop	Wood density [kg.m^{-3}]	Moisture content of the wood [%]	Workshop temperature [°C]	Relative humidity of the workshop [%]
Training and Experimental Forest Range "G. Avramov"	530	30.9	24.8	62.7%
Training and Experimental Forest Range "Petrohan"	550	38.4	26.1	65.5%
"Petnop" Ltd.	500	28.4	10.3	60.4%.

Before starting the experiments, sharpened cutting tools were installed, since the wear of the cutting edges has a significant influence on the final results. Since the researched wood species is the main one used in the "G. Avramov", the cutting tools used in the vertical band saw machine are two, and the experimental studies carried out are of a larger volume.

Figure 4 graphically presents the results regarding the influence of feed speed on the obtained surface roughness. It shows that the results obtained with the circular machine are the best and the roughness varies from 90 to 150 µm, which corresponds to classes VI and VII. The main reason for this is the higher cutting speed of this machine, as well as the higher edge resistance of the cutting tool. As expected, when the feed speed increases, the roughness also increases, but the differences between the low and high values of the studied parameter are minimal. This is mainly due to the fact that the machine is designed to operate at higher feed rates, and this range of variation is kept solely for the purpose of comparability of results. Also for the circular machine, it is noticed that the total amount of cut materials 24.9 m^2 has practically no effect on the roughness of the surfaces, and the discrepancies in the results at similar feed rates are a result of the anatomical structure of the studied material.

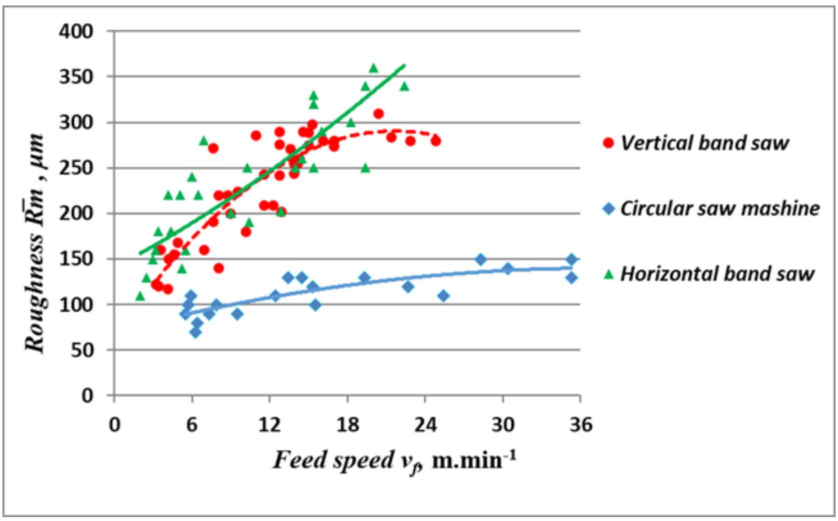

Figure 4: Effect of feed speed on roughness in the machines under study

The worst results in terms of surface roughness were obtained when cutting with a horizontal band saw. They vary from VI to IV class of roughness, with the lowest values of 110 – 150 µm obtained at the beginning of the experimental studies – at a feed speed of 2 – 3 $m.min^{-1}$ and an amount of sawn wood up to 12.9 m^2. With this machine, after a feed speed of 15 $m.min^{-1}$, it is difficult to obtain a roughness class higher than V (200 – 320 µm). The same applies after cutting approximately 32 m^2 of wood.

The resulting surfaces after cutting with the vertical log saw are class VI and V, with a large difference between the ridge line and the dip line within the base length of 310 µm. However, this result was obtained after cutting approximately 64.4 m^2 of wood, i.e. about twice the amount cut with the horizontal band saw.

During the experimental studies, boards with thicknesses of 25 – 30 mm were obtained. When referring to the standard BDS EN 1313-1:2010, it was found that the permissible deviations for these thicknesses are + 3 mm and – 1 mm, at a wood moisture content of 20%. In the current study, the absolute values of the obtained discrepancies between the specified and received dimensions of the boards were reported. However, most of the results were obtained with a plus sign. Figure 5 shows that the best results for this indicator are obtained again with the circular saw machine. With it, the results with negative deviations are less than 0.5 mm, and the largest deviation of 2.1 mm was obtained at an average feed speed of approximately 30 m.min^{-1}. The main reason for this is the better stability of the cutting tool. As with the roughness results, for the dimensional accuracy, the discrepancies between the results are again due to the anatomical structure of the wood and not to the wear of the cutting tools.

The largest deviations were obtained in the horizontal band saw, as after exceeding a feed speed of 15 m.min^{-1}, the quality of the surfaces visibly deteriorated and exceeded the permissible deviations with positive and negative signs. The reason for this is that such feed rates are not characteristic of these machines, and the cutting tools themselves lose their transverse resistance and begin to curve. In addition, a formula provided by Prof. Bershadsky for the critical cutting force at which the band saw blade begins to bend is found in the literature (Bershadsky and Tsvetkova 1975). This formula includes the parameters of the cutting saw – thickness and width. Also, the thickness is squared, i.e. its influence is greater. In addition, the *W* tooth profile has a small gullet, which hardly accommodates chips at higher feed speeds.

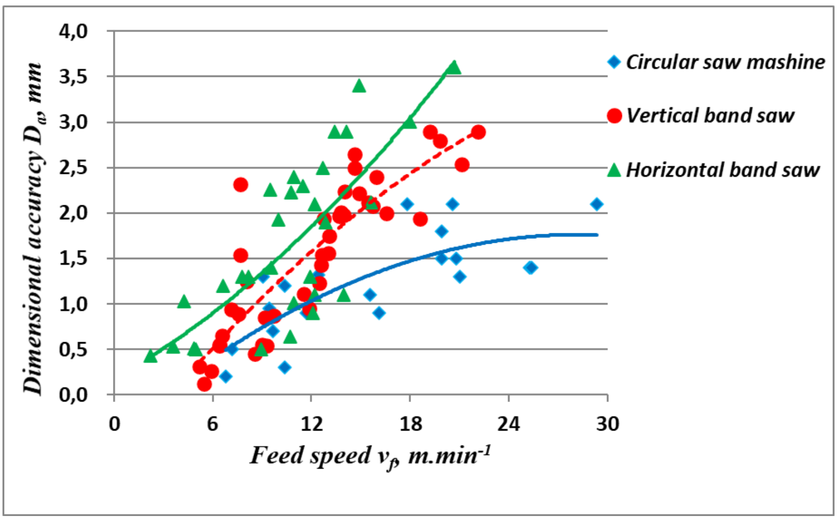

Figure 5: Effect of dimensional accuracy on roughness in the machines under study

The results for the accuracy of the boards, obtained with the vertical band saw machine, can be considered good since the larger values of the deviations in the nominal dimensions – from 1.5 to 2.9 mm have a positive sign. However, when the feed speed exceeded 40 m.min^{-1}, results outside the acceptable range were also obtained.

The productivity of the machines is defined in m^2.min^{-1} as the multiplication between the feed speed and the average cutting height. The arithmetic mean value for cutting ten boards with a normal for the machine feed movement value, depending on the cutting height, was determined. Figure 6 shows the results for this indicator. The average productivity for the circular saw machine is 11.47 m^2.min^{-1}, which is approximately 2 times greater than that of the vertical band saw machine (5.18 m^2.min^{-1}). It should also not be overlooked that the *USTUNKARLI LTD* band saw under study is a relatively lighter type of this machine with a wheel diameter of 1,000 mm, and it is not advisable to feed the logs at a higher feed rate with it. This means that the results on this indicator would be different if a heavier type of band saw was used – for example, *Bongioanni SNT 1600-1800* (www.bongioanni.com). The normal value of the feed speed for horizontal band saws, where the feed movement is carried out by the cutting mechanism with stationary processed material, is from 5 to 15 m.min^{-1}. For this reason, the average productivity obtained is 1.89 m^2.min^{-1}.

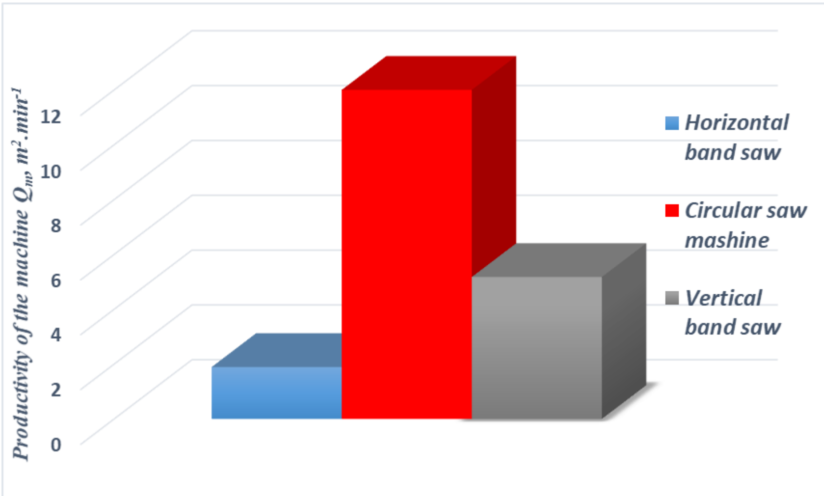

Figure 6: Productivity of the machines studied

CONCLUSIONS

Based on the results of the conducted experimental research, the following more important conclusions and recommendations can be made:

1. The feed speed is an important parameter that characterizes the cutting process and the productivity of the machines. On the basis of the conducted experimental studies, it was found that when cutting Scots pine with a mobile horizontal band saw, it is not recommended to exceed 15 m.min^{-1} and 37 m.min^{-1} with a vertical band saw. The reason for this is that above these values, the cutting tool sharply loses its stability and the resulting deviations from the nominal dimensions exceed the permissible ones.

2. When sawing Scots pine with a circular log machine, from the point of view of dimensional accuracy, the feed speed can reach 100 m.min^{-1}. However, such high values of this parameter are not preferable since the inertial force resulting from the mass of the log and the carriage loads the feed mechanism.

3. Regarding the roughness, the obtained class for the circular machine is from VI to VII, for the band saw with carriage feeding mechanism V to VI and from IV to VI for the band saw with the horizontal composition of the cutting mechanism. In addition, the circular machine, whose cutting tool has carbide plates, did not notice any deterioration in quality due to its wear. Cutting edge wear was most evident in the narrowband saw, after only 32 m^3.

4. Despite its significantly higher productivity (11.47 m^2.min^{-1}) in comparison with the vertical band saw (5.18 m^2.min^{-1}) and especially in comparison with the horizontal band saw

1.89 m.min^{-1}, when cutting logs with circular saws with larger diameters, one significant drawback remains. It is the larger width of cut that reduces the quantitative yield.

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