Improving the quality of the band saw cut

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Abstract. This article is devoted to the study of the dynamic characteristics of the band sawing process to improve their efficiency. The object of study is: band saw, softwood. A screening experiment was carried out when sawing with band saws to identify key influencing factors on the quality of the treated surface (roughness) and sawing force (sawing power). Rational values of key influencing factors were determined. The effectiveness of the sawing regimes with band saws was evaluated. In the course of laboratory tests of the new saw, it was found that the moisture content of the wood has the maximum effect on the quality of the sawing walls. According to the degree of influence of factors, the roughness of the cut depends on the moisture content of the wood, the feed per tooth, the type of cutting relative to the wood grain and the height of the cut. As a result of a multivariate experiment, two regression equations were obtained for the assumed roughness of the cut and the cutting power. The estimation of the significance of the coefficients in the given interval of variation of the influencing factors is carried out.

1. Introduction
The article is devoted to the analysis of the main power and quality indicators of the band sawing process. The object of research is softwood from pine and softer. The research was carried out with a new band saw and riving knife. Although for such a saw, the use of a knife is not necessary, since there are special guide teeth. As a result of laboratory tests of a new band saw with optimal angular and geometric parameters, the energy consumption of the band saw sawing process when processing soft wood has been reduced, namely: cutting speed, feed per tooth, widening of the cut, wood moisture and others. All this made it possible to reveal with sufficient accuracy the economic efficiency of using such band saws in woodworking. The analysis of modern band saws, its geometric parameters, taking into account the current stresses when sawing softwood [1,2]. Most of the works of G F Prokofiev devoted to the processes of sawing with band saws. But he did not investigate the issues of sawing modes for relatively dense and soft wood [4,5]. The available work does not establish the development of saw parameters due to the special deformation-strength properties of softwood wood [6,7]. At the first stage of research, using the original stand, the elasticity and plasticity coefficients for soft deciduous wood were accurately determined, which made it possible to calculate the difference in the height of the main and undercut saw teeth in order to compensate for the elastic recovery of wood fibers. The obtained data on the coefficients are in good agreement with the studies of other authors [8,9]. Accuracy of sawing on a band saw is the main limiter of the feed rate, therefore a series of experiments was set up to study the accuracy of sawing. The implementation of the four-factor experiment made it possible to obtain two
regression equations for determining the roughness of the sawn surface and the energy consumption of the sawing process. The significance of the coefficients was assessed and it was found that the value of roughness of sawn timber for softwood is practically proportional to the width of the cut and at a feed rate of less than 2 m/min the width of the cut practically does not affect the quality of the sawn surface [10]. In work [11], studies of the influence of the feed rate per tooth on the sawing accuracy were carried out. It is argued that the feed rate does not significantly affect the accuracy and efficiency of the band saw. The efficiency of sawing with a band saw is described in a similar way in [3]. However, the opposite opinion was formed in works [4,6]. The influence of wood moisture on the efficiency of sawing soft wood with band saws is also ambiguous [12,13]. The rational value of wood moisture content during the sawing process is not established. Therefore, the purpose of the research was not only to substantiate the parameters of a new band saw, but also to establish the main influencing factors on the efficiency of sawing softwood, as well as operating modes of band saws [14,15]. The practical significance of the planned research is aimed at reducing the energy consumption in the processes of sawing soft deciduous wood with a band saw, as well as increasing the productivity and quality of the treated surfaces in the processes of sawing wood [15,16].

2. Materials
With an increase in the amount of processing of soft wood with band saws and special export requirements, it is necessary to increase the productivity and quality of sawing such wood. Therefore, the main task of our applied research was precisely the solution of this problem. Special studies were carried out to identify the special elastic-plastic properties of hardwood wood and a saw design was developed, which allows to obtain, along with high productivity, an improved sawing quality by reducing the vibration of the saw during cutting and sealing pads on the cutting teeth. The high efficiency of using the new band saw was confirmed by subsequent laboratory tests. Cutting quality improved by 30% compared to standard saws [17]. The invention relates to the field of woodworking industry, in particular to band saws for high-performance and high-quality division of the main industrial wood species. The band saw includes a body 1, main teeth 2, made straight-sharpened, scoring teeth 3, which are smoothing and made skew-sharpened (figure 1). Each main 2 and undercut 3 teeth is made with a contact pad 4. The difference in heights between main 2 and undercut 3 teeth is 0.5 mm. Between the main 2 and scoring 3 teeth there are guide teeth 5, the height of which is equal to the height of the main teeth 2. In this case, the contour of the guide teeth 5 does not protrude beyond the outer contour of the saw. The band saw increases the productivity of the sawing process and reduces the roughness of the surfaces to be cut.

At the second stage of the experiments, based on the method of expert assessments, the influencing factors and the intervals of their variation were determined (table 1).

| Designation of factors | Name                                      | Unit of measurement | Limits of variation |
|------------------------|-------------------------------------------|---------------------|---------------------|
| \( x_1 \)              | Wood moisture                             | %                   | 15  38  60           |
| \( x_2 \)              | Oblique (angle of inclination of fibers)  | degree              | 0   10  20           |
| \( x_3 \)              | Kerf width                                | mm                  | 1.2  2.1  3.0        |
| \( x_4 \)              | Feed per tooth                            | mm                  | 0.04  0.17  0.3      |

The adequacy of the models obtained as a result of the laboratory experiment was checked by the Fisher criterion [17]. Then, using the methods of regression analysis, diagrams of the significance of the
coefficients of the regression model for the sawing power and for the roughness of the sawn surface were plotted.

At the third stage of the research, the analysis of cutting modes with a new band saw [15,17] was carried out on an industrial band saw “Spectrum SR3-200” with a series of two-factor experiments [16]. In each of the experiments, at least 50 measurements were carried out to eliminate the statistical error.

Figure 1. Band saw.

The experimental setup allows to fix the extreme (initial), extreme lower (at maximum compression) and intermediate (after partial extrusion) positions of the lower working edge of the punch, and, therefore, calculate the values of all three types of deformations [15].

The diagram of the experimental setup, which is a vertical pile driver, is shown in figure 2. The installation consists of a bed 2 (figure 2), a hammer 4, which holds the load 3, a latch 1 holding the hammer in the upper position, and a press consisting of a hammer 5, guide rods 6, punch 7, die 8, holder 9, a crusher 10, which is a column of plasticine and a recording device 12. Position 11 shows the location and position of the test wood sample [15].

Figure 2. Scheme of the experimental setup.

3. Results and discussion
The elastic-plastic characteristics were refined on an original laboratory device using the method of mechanical recording of stresses. Based on the registration of the output types of deformations in wood of various soft species, the coefficients of elasticity and plasticity were measured (Table 2). To increase the accuracy of the experiment, the moisture content of the wood was measured by the weight method.

The research results show that under specific loads in the aspen wood sample when it is compressed in the axial direction, both elastic and residual deformations occur simultaneously. As a result of laboratory tests of softwood samples, it was found that when compressed in the axial direction, elastic and permanent deformations are simultaneously formed in the samples. In addition, with an increase in humidity from 10 to 30%, all deformations increase proportionally.
Table 2. Rheological coefficients of softwood elasticity and ductility.

| Odds | Breed   | Humidity of wood,% |  |  |  |
|------|---------|--------------------|---|---|---|
|      |         | 10                 | 20| 30|
| $K_e$| Alder | 0.48               | 0.47| 0.44|
|      | Aspen | 0.45               | 0.40| 0.35|
|      | Linden| 0.42               | 0.39| 0.33|
| $K_p$| Alder | 0.72               | 0.74| 0.79|
|      | Aspen | 0.61               | 0.64| 0.68|
|      | Linden| 0.55               | 0.58| 0.60|

The measured rheological coefficients show that even at low pressure, it leads to rupture and compaction of the vessel walls in the wood (figure 3).

Figure 3. Microstructure before and after deformation (Scale 1:50).

It has been established that the power to the tooth and the wood moisture have the greatest influence on the sawing power and roughness of the treated surface. The rational values of these factors are revealed: wood moisture 15-20%, feed per tooth 0.06-0.1 mm. To ensure the required quality of sawn products, it is necessary to choose the right feed rate [15].

The research results show that under specific loads in a specimen of aspen wood when it is compressed in the axial direction, both elastic and residual deformations occur simultaneously. In this case, the value of the relative residual deformations at all values of the specific load exceeds the value of the elastic deformations. With an increase in the specific load, all three types of deformations increase with constant deceleration, which is explained by an increase in the density of wood as it is “pressed”. With an increase in the moisture content of wood from 10 to 30%, the deformability of wood increases, which is confirmed by an increase in all three types of deformations.

With an increase in the shock load, the walls of the vessels burst and the destruction of the samples is possible, already at $A = 80$ J/cm$^2$.

$$t_k = \mu \cdot (K_r + K_p), \text{mm}$$  \hspace{1cm} (1)

where $t_k$ is the difference between the radii of the teeth, which is necessary to compensate for the elastic recovery of the fibers; $\mu$ – coefficient of friction along the back surface of the cutter, for soft deciduous wood equal to 0.19.

Regression models for the roughness of the sawn surface and power after screening out insignificant coefficients of the regression equation are as follows:

$$R_m(W, K_r, B, S_z) = -153.87 + 6.31W + 3.86K_r + 78.8B + 502.6S_z - 1.19K_rB - 2.05WB - 9.19WS_z + 56.62BS_z$$ \hspace{1cm} (2)

$$N(W, K_r, B, S_z) = 557.31 - 1.19W - 10.15K_r - 7.96B - 498.32S_z + 3.34K_rB - 0.7WS_z + 3.34K_rB + 20.83BS_z + 4.38K_rS_z$$ \hspace{1cm} (3)

Figure 4 shows a diagram for determining the significance of the coefficients of the regression model.
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Figure 4. Diagrams of the significance of the regression coefficients for the power for
sawing wood (a), surface roughness (b) from the factors: A – humidity, B – cross-bedding,
C – kerf width, D – feed per tooth.

The verification of the adequacy of the obtained models showed that the value of the Fisher design
criterion is greater than the tabular one, i.e. the indicated mathematical models adequately describe
the process of sawing softwood. On the basis of a comparative analysis of the roughness and thickness
variation of sawn timber, it was found that the maximum value of the roughness of pine boards grows
with an increase in the feed rate more intensively, in comparison with other species, the nature of the
dependence of quality on the kerf width is the same for all the species under consideration – it is close
to linear, and it is also established, that the dependence of the coefficient of thickness difference for pine
and aspen boards is significantly nonlinear. The technological process of sawing softwood wood with
band saws is adequately described by the obtained dependencies, which make it possible to determine
its parameters and evaluate the efficiency of the sawing process. The possibility of intensifying the
sawing process with an experimental model of a band saw has been established. To ensure the required
quality of sawn timber, it is necessary to choose the correct feed rate. The nature of the dependence of
the roughness Rm max on the kerf width is the same for all considered breeds - it is close to linear.

4. Conclusion
Experiments have established an increase in the accuracy of sawing wood using a new band saw by
improving the stability of its operation (reducing vibrations, smoothing the kerf walls). With an increase
in feed per 1 saw tooth, cutting accuracy also decreases due to an increase in friction against the saw cut
and an increase in lateral forces. But the maximum influence on the roughness of the cut has the moisture
content of the wood. The optimum humidity should be considered to be no more than 15%, with a feed
of up to 0.5 mm per tooth.

The rational values of the factors that have the maximum effect on the quality of the cut - feed per
tooth and permissible moisture content for soft wood have been determined. As a result, the quality of
sawn products is determined by four main factors according to the degree of their influence: wood
moisture, feed per tooth, type of cutting in relation to the fibers and cutting height.

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