Improving the construction of grinding disk mill for producing fibrous semi-finished products

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Abstract. The article states that grinding is the most important process; it determines the efficiency characteristics of the fibrous semi-finished product and the properties of the products made of it. The effectiveness of this process is influenced by some factors, but a tackle is of the most importance. Recently, the issues of selecting and creating the tackle design for wood fibers preparing, in contrast to cellulose and waste fibers, remain significant. In this regard, a scientific approach to solving the issue of creating the tackle design is required for the effective preparation of high-quality wood fibrous semi-finished product. The article presents theoretical studies for efficient evaluation of the existed structures for grinding wood fibbers in disk mills. It has been a basis for developing a new geometry of the tackle and predicting its efficiency along with numerous preliminary studies and investigations carried out by various authors. The results of the experimental studies of the grinding process applying the existing structure and the results of the simulated experiment with the developed geometry of the tackle are presented. A comparative analysis of the influence of the design features of various types of tackles on the dimensional and efficiency characteristics and fractional composition of the semi-finished wood fibers was carried out. It was carried out on the basis of the theoretical and experimental studies, as well as the results of other authors studies concerning a grinding process and the influence of the of the semi-finished product features in the preparation of a fibrous semi-finished product in a disk mill.

1. Introduction
Nowadays, fibrous semi-finished products are the basis for the production paper, cardboard, and various types of fiberboard in the pulp and paper as well as timber industries. Their efficiency indicators determine the final properties of the finished product directly.

The initial raw material for the production of fibrous semi-finished products is chipped wood [1–4]. It is subjected to blade grinding in disk mills after preliminary chemical or thermal processing. The milling process is the most important technological stage, where, under the influence of the blade elements of the mill, fibers get certain characteristics, properties, and composition [3–4]. The main parameters of the grinding process are the concentration of the mass, a value of the working gap between the grinding discs, a pattern of the working surface of the tackle, etc. Their regulation determines both the efficiency of the resulting semi-finished product, the productivity and efficiency of the grinding equipment, and the entire production process [3–4]. The grinding tackle is a working body of disk mills, where the structural elements of the working surface (a position angle of the rotor and stator blades, their width and inter-blade cells, etc.), along with other factors, determine the efficiency of the influence
on fibers (fibrillation or shortening) and their characteristics of the grinding process [3–7]. Currently, scholars of the scientific school supervised by Professor Yu.D. Alashkevich, have investigated issues related to the development of new types of tackle design and their influence on the grinding process of cellulose fibers [4, 5, 7]. Meanwhile, the issues connected with the influence of the tackle design in the preparation of wood fibers have not been fully investigated. The construction of the tackle for grinding wood fibers used in industry has a double-sided design. According to the studies of the authors [3–5, 7], it entails an undesirable shortening of the fibers, not providing the necessary dimensional and efficiency characteristics of the semi-finished product and its composition. Hence, the efficiency of grinding machines, quality and environmental friendliness of manufactured products reduces. This can be explained by the fact that the tackle has been of the same type for a long time. When it was created, they relied more on the practical experience of production workers without a scientific and theoretical base, which would make it possible to make an informed choice of a particular pattern of the tackle that provides the required efficiency characteristics [3].

So, the research aimed at the development and improvement of the working surface of the grinding tackle using a scientific approach, will improve the efficiency of the grinding process in the existing grinding disk mills, providing the improvement in the quality characteristics of semi-finished wood fibers and the physical and mechanical properties of various types of finished products.

2. Materials and research methods

2.1 Theoretical research methodology
The main design and technological parameters were determined in application of the specially developed techniques in works of authors [5, 7] applying modern software (KOMPAS 3D, Matlab) in order to assess objectively the effectiveness of the impact of the tackles. They characterize the efficiency of the grinding process in a disc mill of the existing geometry of grinding tackle for the preparation of the semi-finished wood fibers in comparison with the developed tackle.

In order to evaluate the effectiveness of the set in the process of preparing fibrous semi-finished products on high-speed knife disk mills efficiently and fully, the authors [4–5] developed the technological parameter a "cyclic elementary length Lω.el.", calculated by the formula (1)

\[ L_{\omega,el.} = \frac{L_s \cdot 60}{n \cdot t \cdot (2\pi / \psi)} \]  

where \( t \) is the number of moving points of intersection of the rotor blades with the stator blades, pcs; \( n \) is rotor speed, rpm; 
2\( \pi / \psi \) is the number of sectors.

The cyclic elementary length (Lω.el.), characterizes the average length of the fibers, "cut off" by a pair of blades in one rotation of the rotor relative to the stator. With the help of this parameter it is possible to evaluate the efficiency of the grinding process in the direction of shortening fibers or obtaining a long-fibers fraction with fibrillation.

The articles [3–5,7] proved that with an increase in the number of contact points, the cyclic elementary length index decreases. It characterizes an increase in the shortening effect and leads to a deterioration in the grinding efficiency.

2.2 Technique for conducting experimental research
Investigations of the process for preparing wood-fibers semi-finished products were carried out at the laboratory of the Defibrator type VA applying the existing design of the tackle for the preparation and dissolution of fibrous semi-finished products at the second stage of grinding on the basis of the laboratory “Timber processing pulp and paper and chemical wood technology” of the Lesosibirsk branch of Reshetnev Siberian State University. The initial raw material was wood fibers after the defibrator (degree of grinding DSD=11 DS, average fibers length La=8 mm, da=0.3 mm), obtained from mixed
species of softwood (100%) at the plant for the production of fiberboards OJSC SegezhaGroup "Lesosibirskiy LDK No. 1".

A one-factor experiment was carried out, all other things being equal in the technological process for the semi-finished wood fibers production, in the disk industrial equipment. The main input parameters, levels and steps of their variation for planning a one-factor experiment were determined on the basis of preliminary studies: working gap between grinding discs is $(0.05 \pm 0.01) \text{ mm} \leq g \leq (0.15 \pm 0.01) \text{ mm}$; wood fibers mass concentration is $(2 \pm 0.1) \% \leq s \leq (4 \pm 0.1) \%$. The quality characteristics of the semi-finished product were selected as output factors: degree of the wood fiber pulp grinding (DS); average fiber length $(L_{av}, \text{ mm})$; average fiber diameter $(d_{av}, \text{ mm})$; ratio of length to diameter of fibers $(L/d)$ and the content of coarse $(F_l, \%)$, medium $(F_m, \%)$, small $(F_f, \%)$ fiber fractions of the total mass.

Efficiency indicators of semi-finished wood fibers and its fractional composition were determined using the equipment ("Defibrator-second", fractionator FVG-2, digital microscope Hitachi TM-3000), according to the well-known techniques [3].

As a result, the obtained values of the dimensional and efficiency characteristics of the wood-fibers semi-finished product were the basis for the efficiency and quantitative evaluation of the experimental results, the construction of statistical and mathematical equations that describe the studied adequately. This made it possible to carry out an objective comparative analysis and predict the efficiency results of the preparation of semi-finished wood-fibers products on operating grinding tools using the existing geometry (patterns) and the developed surface of the grinding tackle segments. The processing was carried out applying modern software packages Statistica 6.0 and Microsoft Excel 2007 in order to describe an object with the least squares method according to the known techniques [8]. The obtained mathematical models describe the process under study adequately. The coefficients of each factor are significant. The significance evaluation of the regression coefficients was carried out according to the well-known technique [8], using the Student's $t$-test. The results of theoretical and experimental studies made it possible to predict and simulate the grinding process applying the developed geometry of the tackle, all other things being equal in production conditions.

### 3. Experimental part, results and their discussion

Some authors proposed the geometry of the grinding tackle for the effective preparation of the wood-fibers semi-finished product in a disk mill, which can provide the possibility of increasing the fibrillation. It was done on the basis of numerous theoretical and experimental studies related to the study of the mechanism of the grinding process of fibrous semi-finished products, the influence of various process factors, in particular the design features of the grinding tackle.

A generalized table 1 was obtained on the basis of the results determining and calculating the technological parameters of the existing grinding tackles in comparison with the developed tackle and taking into account the peculiarities of their structural elements.

| Table 1. Design features and technological parameters of blade tackles. |
|---------------------------------------------------------------|
| **Grinding tackle for the preparation of semi-finished wood fibers** |
| **Traditional (P-1000.015)** | **Laboratory (Defibrator VA)** | **Developed** |
| Design features | | |
| width of the blade, $\delta$, mm | 3 | 5.5 | 6 |
| width of the blade cell, $L$, mm | 9 | 7.5 | 8 |
| depth of interblade cell, $h$, mm | 9 | 7.5 | 8 |
| angle of installation of the 1st rotor blade, $\alpha_{2r}$, ° | 12.4 | 0 | 22 |
| angle of installation of the 1st stator blade, $\alpha_{1}$, ° | 168.2 | 20 | 22 |
| intersection angle, $\alpha_{cr}$, ° | 24.2 | 10–30 | 0–20 |
| outer diameter, mm | 1000 | 1000 | 1000 |
| **Technological parameters** | | | |

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Table 1 shows that the developed geometry of the tackle, in comparison to the existing ones, makes it possible to reduce the values of the blade intersection angle (αcr.). The number of blade contacts formed when intersecting (t) in two or three times. As a result, it provides an increase (in one and a half to two times) values of cyclic elementary length and grinding surface, characterizing the high efficiency of the grinding process. According to some theoretical studies [3,4,5,7], a decrease in the intersecting angle and the number of contacts formed when intersecting blades of the tackle, with an increase in the main technological parameters, may indicate an increase in the proportion of normal forces under the action of the tackle. It ensures effective splitting of fibers mainly along its axis (fibrillation). The confirmation of the high efficiency of the blade tackle and the grinding process can be a consequence of the destruction nature with the increase in the proportion of long and thin, flexible fibers in the total mass of the semi-finished product [3].

The graphical interpretation of the obtained results is presented in figure 1.

**Figure 1.** Dependence of the efficiency characteristics and fractional composition of the wood fibers semi-finished product on the working gap between the grinding discs (a) and mass concentration (b).

It can be seen in graphs in figure 1a that there is a decrease in the increase in the degree of grinding with an increase in the working gap between grinding discs (g), as a result of a decrease in the specific pressure and, accordingly, a cutting effect. At the same time, an increase in (g) within the range of up to 0.08-0.11 mm promotes intensive splitting of fibers in the longitudinal direction. The ratio of their length to diameter L/d increases (for the laboratory ≈50-57, for the developed ≈65-71), mainly, due to a decrease in the diameter. A further increase in the working gap entails a decrease in the intensity of the
grinding process. This negatively affects efficiency characteristics of the semi-finished product. Figure 1b presents an increase in the concentration of wood fibers pulp (c) has a positive effect on the quality characteristics of the semi-finished product. An interlayer in the gap between the rotor and stator blades increases with an increase in the mass concentration. Bundles of fibers and separate fibers are intensively abraded against each other with a decrease in the direct blade action, i.e., gentle grinding occurs. It helps to maintain the length of the fibers while reducing their diameter; formation of thin, long and flexible fibrillated fibers with a high L/d ratio increases.

It is worth noting that the influence of the working gap between the grinding discs and the mass concentration on the quality indicators of the wood-fiber semi-finished product has a similar qualitative nature, both when using a laboratory tackle and the developed design. However, the application of the developed tackle provides an increase in efficiency indicators and an improvement in the ratio of various fractions of fibers in the total mass of the semi-finished product due to the fibrillating effect.

Table 2 presents comparative results of the grinding process of wood-fibers semi-finished product on different types of tackle, all other things being equal.

| Tackle geometry      | Efficiency characteristics and fractional composition of wood-fibers semi-finished product |
|----------------------|--------------------------------------------------------------------------------------|
|                      | DS | F_i, % | F_m, % | F_r, % | L_a, mm | d_a, mm | L/d       |
| Traditional (P-1000.015) | 20 | 28-30  | 26–27  | 44–45  | 5.1–5.3 | 0.12–0.13 | 40–48    |
| Laboratory (Defibrator VA) | 20 | 24-26  | 34–35  | 38–39  | 4.7–4.9 | 0.085–0.09 | 52–57    |
| Developed            | 20 | 23-25  | 42–43  | 32–33  | 4.4–4.6 | 0.065–0.07 | 65–71    |

Tables 1 and 2 show that higher values of indicators are observed for the developed tackle, i.e., an increase in the technological parameters of the tackle (almost twice) with a decrease (almost two or three times) in the number of contact points of the rotor blades with the stator blades (t. pcs.). As a result, the geometry of the working surface of the tackle of the developed design, in comparison with the existing ones, during the grinding process will provide a semi-finished product with a predominance of the middle fraction (F_i, %) in the total mass: developed (42–43), laboratory (34–35), traditional (26–27), with a decrease in the fine fraction (F_r, %), i.e., developed (32–33), laboratory (38–39), traditional (44–45). In general, geometric characteristics of the semi-finished product are improved. A more intense (one and a half to two times) decrease in the diameter of fibers (d_a, mm) is observed, i.e., developed (0.065–0.07), laboratory (0.085–0.09), traditional (0.12–0.13) than their length (L_a, mm), i.e., developed (4.4–4.6), laboratory (4.7–4.9), traditional (5.1–5.3), contributing to an increase (by one and a half to two times) the ratio of the length of fibers to their diameter (L / d), i.e., developed (65–71), laboratory (52–57), traditional (40–48).

4. Conclusions
The predicted effect of using the tackle of the developed design in the grinding process is confirmed by theoretical data related to the determination of the movement of rotor’s blades and stator tackle relative to each other forming an intersecting angle.

The articles [3–4, 7] state that with a decrease in the intersecting angle and the number of contacts of the rotor’s blades with the stator blades, an increase in normal influences on the fiber is provided. As a result, the fiber is destroyed along weak bonds in the longitudinal direction. Therefore, it is necessary to strive for the prevalence of normal components forces, in contrast to tangents acted in the transverse direction.

According to the theoretical data [3, 5, 7], the developed design is characterized by a decrease in the intersecting angle and the number of contacts, with an increase in technological parameters. It indicates an increase in the proportion of normal force components than tangents, which may confirm the possibility of intensive development of wood fibers in the direction of their fibrillation.
Thus, the results of theoretical and experimental studies can confirm the predominant efficiency of the grinding process when exposed to a wood-fiber semi-finished product of the developed design in comparison with the existing tackles for preparation. As a result, the developed geometry of the tackle can provide an improvement in the efficiency characteristics and the ratio of various fractions in the total mass with a predominance of thin and long flexible fibrillated fibers capable of good interaction. According to the authors' studies [3, 4], it contributes to an increase in the strength properties of various wood fiber products. In the course of experimental studies, the significant effect of the working gap between the grinding discs of the tackle (g) and the mass concentration (c) on the dimensional and efficiency characteristics and the composition of the semi-finished product was confirmed. According to the obtained results, we can conclude that a wood-fiber semi-finished product with the best dimensional and efficiency characteristics can be obtained with the following parameters of the grinding process: \( g = 0.08–0.11 \) mm; \( c = 3–3.5\% \).

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