JUSTIFICATION OF PARAMETERS OF HEMP STEM ROLLERS

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Abstract. The object of the study is technological processes, hemp stalks, stalk flattening, flattening working bodies. The interaction of the working bodies of flattening rollers with hemp stalks, the influence of their parameters and operating modes on the efficiency indicators of the technological process of preparing tress is the subject of the research. The features of the interaction of the stalk with the rollers under conditions of linear pressure change are considered. According to the results of theoretical studies of flattening hemp stalks, the following were obtained: a mathematical model of the interaction of smooth flattening rollers with a cone-shaped stalk; graph-analytical dependencies for substantiating flattening conditions; dependencies of the maximum value of the generalizing reaction, the normal component of the reaction and the friction force on the intensity of the load, the angle characterizing the maximum arc of contact of the stalk and the radius of the rollers. The above allowed us to establish rational values of the roller radius of 75-85 mm, the gap between the rollers of 2.2-4.5 mm and the length of the rollers of 380-420 mm. Analytical dependences of the radius of the flattening rollers on the length of the conical stem, the outer radius of its upper part, half of the flattened part, the angle characterizing the initial moment of contact of the stem with the rollers have been established. A dependence has been established to determine the angle characterizing the initial moment of contact of the conical stem with the rollers depending on the stem parameters (length, outer radius of its upper part, half of the flattened part), the structural parameters of the flattener (radius of the flattening rollers).

Keywords: hemp stalks, stalk flattening, working bodies, mathematical model.

Introduction

Until recently, the mechanical destruction of hemp stem structure (straw, pulp) was primarily considered either as calendering to break bonds between fibrous tissue and wood, or as crushing the stem wood to weaken its bond with the fiber. That is, the technological processes of calendering and crushing hemp (straw, pulp) were applied mainly to already prepared pulp.

Hemp stem calendering, along with other potential factors, should be considered as a key method that enables intensification of biological processes in pulp preparation. The research results convincingly demonstrate the prospects of using the stem calendering operation and its significant contribution to reducing costs and improving the quality of raw materials and products [1; 2].

The gradual adjustment of the gap between the rolls improves not only the process controllability but also ensures a uniform destruction of the stems' outer shell [3; 4].

The authors [4; 5] noted that under conditions of uniformly distributed contact of the stem with the rolls over the entire surface, and if the horizontal component of the friction force exceeds the values of the horizontal component of the rolls' pressure on the stem, the stem is pulled into the gap between the rolls. Under the opposite conditions, the stems will be pushed out.

Studies [6, 7] have shown that the calendering process efficiency depends on many factors, the main ones being: the calendering roll diameter, the pressure and layer of stems, the thickness of the stem layer being processed, and the physical properties of stems.

Theoretical analysis of the calendering process conducted by a number of authors investigated the forces that create the conditions for separation of bast from the stem wood [8]. However, these studies were based on assumptions regarding constant stem parameters (diameter) and a constant force value.

The authors [9] investigated the effect of pressure changes on the stem layer under the conditions of their passage between smooth rolls in order to disrupt the ribboniness of the bast. The experiments were carried out on a single-roller compactor, the design of which provided for changing rolls with a diameter of 100, 140, 180, and 200 mm. At the same time, the pressure on the stem layer and the speed of movement between the rolls varied widely. Hemp straw was fed to the rolls with the butts forward, perpendicular to the axes of the rolls in a single-stem layer 50 mm wide. The experiments were carried out on hemp harvested from green grass. Handfuls of stems were processed at a humidity of 20-22%. In experiments to determine the patterns of disruption of the connections between the bast and the wood

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due to an increase in the diameter of smooth rolls, the humidity of the stems was 13%. The authors noted that a decrease in the diameter of the rolls contributes to an intensive disruption of the connection between the bast and the wood. This pattern is expressed by a power function.

The authors of [10] established the operational power of a pair of rolls and the peripheral speed of the rolls. In the mentioned work it was noted that the thickness and degree of the stem compression under the conditions of passage between two rolls depended on the roll diameters and the friction coefficient of the plant on the surface of the rolls. Thus, increasing the diameter and friction coefficient ensures compression of stems of a larger diameter, which improves the conditions for stem movement and increases the productivity of the compression process and the degree of grinding of the woody part of the stems [11].

Researchers have presented various models to simulate the energy costs of stem processing. Among these theories, the most well-known and generally accepted are the Kick, Rittinger, and Bond laws of size reduction. Their theories are presented in [7]. However, in these studies, the stems are represented as cylinders.

It should be noted that previous theoretical studies modeling stem-roll interaction used simplified representations of stem parameters. These mathematical models did not take into account the taper of hemp stems, which significantly distorted their results.

Materials and methods

There are two main types of hemp stem length: the total and the technical [2] stem length. The longer the stem, the longer the bast bundle cells and the higher their specific strength. In addition, a long stem contains a greater amount of fiber, which also results in a higher fiber yield per hectare [4].

Hemp plants vary greatly in stem length and thickness. Analysis of different varieties shows that the stem length is at the level of 249.3 cm, and the fluctuation of the average indicators of individual ones varies from 132.9 to 375.6 cm, and the height of some plants can reach a height of 400 cm [2; 4].

The aim of the work is to increase the efficiency of hemp production by substantiating the parameters of hemp stem calender rolls. This will enable intensifying the preparation processes of hemp stem pulp and improve its quality. The cone-shaped hemp stem calendering process is analyzed. The following notations are adopted: d_{11}, d_{21} – inner diameter of the butt and upper parts of the stem; d_{12}, d_{22} – outer diameters of the butt and upper parts of the stem, respectively; l_{st} – stem length; α_1 – stem taper angle; δ_{st} – stem wall thickness. Under the conditions of clamping between two smooth rolls, the stem is compressed from thickness d_{21} to thickness d_n. Stem deformation was defined as $\Delta d = (d_{12} - d_n)$. With such deformation, the outer woody layer of the stem is destroyed.

It is assumed that the thickness of the stem δ_{st} is constant.

The interaction of the stem with the rolls is considered under the condition of moving the stem towards the rolls with its upper part. Then the gap between the rolls is equal to

$$d_n = d_{12} - 2 \cdot \delta_{cm}. \tag{1}$$

The interaction of the stem with the rolls occurs under condition

$$d_{12} > d_n. \tag{2}$$

In case when $d_{12} \leq d_n$, the stem passes through the gap between the rolls without interacting with them. In case when $d_n > d_{22}$, interaction of the rolls with the stem also does not occur. The conical shape of the stem determines the corresponding formation of a conical internal gap.

It is worth noting that the pressure from the rolls on the stem is not distributed evenly. The specific features of the interaction of conical stems with rolls include an increase in the contact arc (respectively, the pressure from the rollers) as the stem moves between them.

Results and discussion

In case when $d_n \approx \delta_{st}$, the calendered stem does not contain various types of voids. Under these conditions, the stem deformation in the initial phase is determined $\Delta d_{\min} = (d_{12} - 2\delta_{st})$. Finally – $\Delta d_{\max} = (d_{22} - 2\delta_{st})$.

The relationship is determined

$$\frac{\Delta d_{\min}}{\Delta d_{\max}} = k_1$$

$$k_1 = \frac{d_{12} - 2 \cdot \delta_{st}}{d_{22} - 2 \cdot \delta_{st}} = \frac{d_{12} - 2 \cdot \delta_{st}}{d_{11} + 2 \cdot (\delta_{st} + l_{st} \cdot tg\alpha_1)}, \quad (3)$$

where k_1 – coefficient that characterizes the change in deformation of the conical stem change depending on its length.

Expression (3) and the graphical correlations constructed from it (Fig. 1) determine the change in stem deformation from its length, parameters (d_{11}, d_{12} and d_{11}, l_{st}).

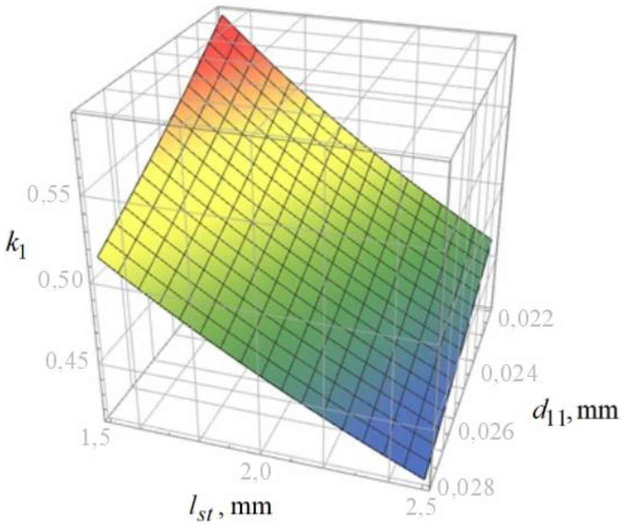

Fig. 1. **Correlation of the change in the coefficient characterizing the deformation of a conical stem on the length of the stem and the internal diameter of the upper part of the stem**

Features of the stem interaction with the rolls under conditions of linear pressure change are considered (Fig. 2). The pressure is directed along the normal to the roll surface. At point a_{1c}, the position of which is determined by the angle ξ_1, normal force is applied $N_1 = q \cdot x_1$, where q – force intensity per unit length ($N \cdot m^{-1}$), x_1– displacement of the stem from the beginning of interaction (contact with the rolls at point a_1) and until the maximum force value is reached at point b (minimum distance between rolls, m).

Forces N_{1v} and F_{T1_v} compress the stem in a vertical plane, and the resultant forces N_{1_h}, F_{T1_h}, which are directed in opposite directions, move the stem between the rolls. The noted displacement will occur if

$$F_{T1_h} > N_{1_h}. \quad (4)$$

Note that (4) can be represented by the known expression

$$\varphi > \xi_1. \quad (5)$$

Expression (5) determines the conditions for moving stems between the rollers.

The position of point a_1 (Fig. 2) is defined by the angle α_{11}. It is assumed that the diameters of flat rollers are equal $D_1 = D_2$. As a result of simple transformations, we obtain

$$R_1 = \frac{3 \cdot (l_{st} \cdot r_{12} \cdot \sin\alpha_{11} + r_{12} - r_n - r_{12} \cdot r_n}{r_{12} \cdot (3 - \sin\alpha_{11})}, \quad (6)$$

$$\alpha_{11} = ark\sin\left[\frac{3 \cdot r_{12} \cdot (R_1 - 1) + 3 \cdot r_n \cdot (1 + r_{12})}{r_{12} \cdot (3 \cdot l_{st} + R_1)}\right]. \quad (7)$$

Expression (7) sets the value of the angle α_{11} (angle characterizing the initial contact moment of the stem with the rolls) for its conical shape based on the stem parameters (l_{st}– length, r_{12} – outer radius of its upper part, r_n – half of the calendered part), structural parameters of the calendering machine (R_1 – calendering roll radius).

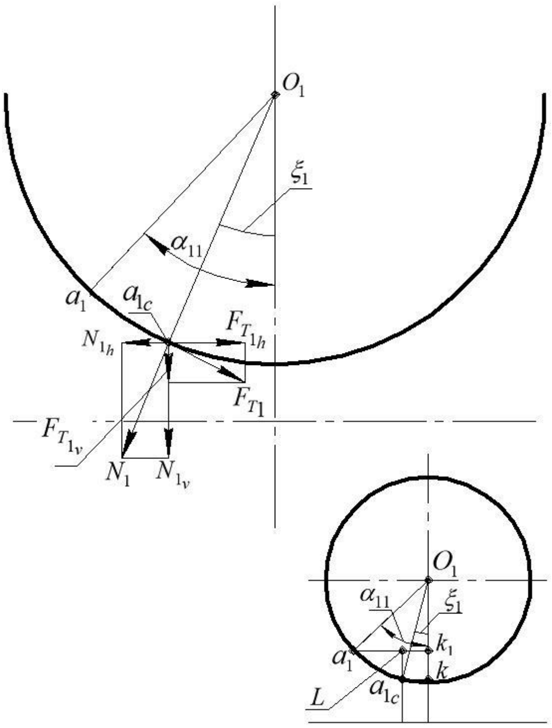

Fig. 2. **Schematic representation of the change in pressure (stem deformation) of the rolls based on the position of point a_1**

The justification of the roll parameters is carried out by the following algorithm. Based on the graphical correlations (Fig. 3, a) using the data of the range of the outer diameter change of the hemp stem's upper part determined in real operating conditions, the range of the roll radius change is determined. The mentioned indicators of the roll radius 75-85 mm (Fig. 3, b) enabled determining the 2.2-4.5 mm variation range of the gap between the rolls.

The roll operation width of 380-420 mm is determined according to the known expression [3].

It is worth noting that the pressure of the rolls on the stem can vary:

1. Uniform $q = const$ $q = const$ does not depend on the contact area (arc length);
2. linearly, i.e. an increase in the contact area leads to a corresponding increase in pressure ($q = C_1 \cdot x$, x – coordinate of stem movement in the horizontal plane);
3. nonlinear

$$q = \sqrt{C_2 \cdot x}\,;\; q = C_2 \cdot x^2\,;\; q = C_2 \cdot x^3$$

where C_1, C_2 – constants;
q – specific pressure per unit length over the entire arc of contact.

Managing the technological processes of hemp production, including pulp preparation stages, is a key factor significantly improving both technical-economic indicators and product quality. In this regard, hemp stem calendering intensifies the biological processes of their transformation into pulp, reduces the time for its preparation, and, thanks to the effective use of the administering solution complex, increases its quality.

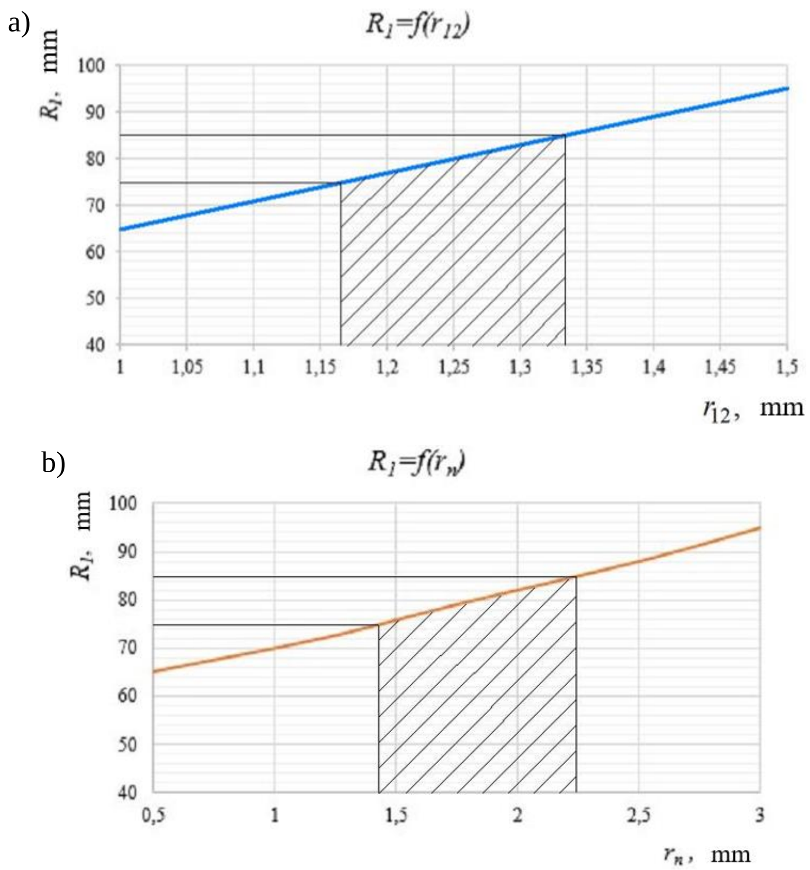

Fig. 3. **Graphical correlations of the change in the radius of the rolls versus:**
a – outer radius of the stem's upper part; b – stem calendering radius

Conclusions

Based on the results of theoretical studies on the hemp stem calendering, a mathematical model of the flat calendering roll interaction with a cone-shaped stem was obtained, as well as graph-analytical correlations to justify the calendering conditions, which allowed establishing rational values of the roll radius of 75-85 mm, the gap between the rolls of 2.2-4.5 mm, and the length of the rolls of 380-420 mm.

Analytical correlations between the calendering roll radius and the conical stem length, the outer radius of its upper part, half of the calendered part, and the angle characterizing the initial moment of the stem contact with the rolls are established.

A correlation is established for determining the angle characterizing the initial contact moment of the cone-shaped stem with the rolls based on the stem parameters (length, outer radius of its upper part, half of the calendered part), and the calender's structural parameters (radius of the calendering rollers).

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Author contributions

Conceptualization, V.S. and Y.S., methodology, V.S. and Y.S., software, V.S., I.D., Y.S., M.T. and T.H., validation, V.S., I.D., Y.S., M.T. and T.H., formal analysis, V.S., I.D. and Y.S., investigation, V.S. and Y.S., data curation, V.S., I.D., Y.S. and M.T., writing – original draft preparation, V.S. and Y.S., writing – review and editing, V.S., I.D., Y.S., M.T. and T.H., visualization, V.S., Y.S. and T.H., project administration, V.S., Y.S. and M.T. All authors have read and agreed to the published version of the manuscript.

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