Modeling of utilization means of oilseed flax stem part

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Summary. The paper shows the results of modeling of the means of processing and recycling of Oilseed Flax harvest stalks. An algorithm which describes the technological process of harvesting Oilseed Flax and processing it into fuel materials is proposed. The evaluation of consumer properties of Oilseed Flax fiber indicates its significant potential as a raw material for textile industry. However, the difficulties that arise in stalking the stems in a stock require the search of new ways of using pulp, which is formed in the process of gathering Oilseed Flax by a combine harvester.

Keywords: Oilseed Flax, Stems, Cutting Surface, Cutter Tooth Model, Destruction, Processing Technology, Utilization.

INTRODUCTION

The development of organic production and the implementation of legislation on the utilization waste of European Union [1] in Ukraine envisages a search of ways and means of processing and disposing of the unproductive part of industrial crops, particularly Oilseed Flax.

The utilization by burning the stem part of Oilseed Flax during its harvesting is a problem of agricultural production in Europe. Burning is unacceptable in the global warming conditions; it also does harm to the environment, since soils are clogged with the fibrous component of the stems, which does not decompose for a long time. In this regard, the problems with the qualitative use of land resources arise. During the gathering of Oilseed Flax with a modern combine harvester, straw rolls remain in the field. They are of considerable size and, as a result, they do not turn into stock for a long time by means of a retting.

Therefore, it is advisable to dispose of the stem part of the Oilseed Flax harvest by its processing in stationary conditions to obtain products for various purposes.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Scientists are actively researching the ways to process and utilize the stem part of industrial crops. A study of consumer properties of Oilseed Flax fiber grown in the conditions of Western Polissya showed [2, 3] that they do not differ significantly from the properties of Fiber Flax. However, the problem lies in the technical means for gathering Oilseed Flax in order to use the maximum potential of the plant - after the separation of seeds, to ensure the mechanization of the processes of formation of stock, its timely selection and processing.

The considerable attention is paid to creating the conditions for preparing stock from flax stems to preserve the quality properties of the fiber, [4, 5,] in accordance with the natural-climatic growing conditions. In particular, scientists of Kherson National Technical University conducted the research on the artificial moistening of Oilseed Flax straw with various chemical reagents to accelerate the laying of stock and the increase in consumer properties of the resulting short non-oriented fiber [6]. But today there are no studies on the production of fiber from Oilseed Flax by the method of retting.

A possible way of solving the problem is also the search of new types of fuel materials [7, 8 - 11]. The peculiarity of producing fuel from such raw materials is their sealing by known methods. It is necessary to apply the appropriate boilers for their use. Oilseed Flax, grown on the territory of Western Polissya, has a powerful energy potential. The scientists of Lutsk National Technical University conducted the research on the production of fuel materials in the form of briquettes by using frozen lacustrine sapropel as a binder. As a result of study the energy potential of the samples and the time of their combustion were obtained. [10].

The presence of short Oilseed Flax fiber in fuel materials complicates the manufacturing process in the form of packages suitable for combustion in serial boilers due to the considerable elastic properties of the stems. However, the production of such fuel bags will allow using of the fiber which not suitable for using in the textile industry. The lack of specialized machines for a given crop leads to significant loss of yield. First of all a significant damage to the stem part of the crop, which affects negatively the fiber production; causes the loss of seeds; stubble that stays in the field, contains fiber and negatively affects the further use of the field; The winding of stems on the working bodies leads to the faults of the combine.

Mechanical damage to the bast part of the Oilseed Flax stems when it is harvested for seeds will accelerate the transformation of the stems into the stock. The use of effective mechanical impact on the processing stage of the stocks will allow the shortest unoriented fiber to be identified as much as possible. The study of the destruction of leaf-stemmed agricultural materials [12-14] indicates the prospect of destruction of the stem part of flax by oil-based mechanized means with rotor drums [12-14]. However, the research on the grinding process of the stem part of Oilseed Flax, grown in the conditions of the Western Polissya, is not available today. Therefore, if the processing of the stem part of Oilseed Flax is to be carried out within certain timeframes, it is possible to obtain good fibrous raw materials for the textile industry. If the stalks lose their quality, it is possible to obtain materials suitable for the manufacture of fuel, geotextiles, building materials, etc. This will help to solve many environmental problems.

The purpose of the research is to prove the possibility of efficient use and ecological utilization of the stem part of the crop of Oilseed Flax grown in the agro-climatic conditions of the Western Polissya. To achieve the goal, the design of the apparatus for the grinding of the bast part of technical crops by cutting method was substantiated and simulated, and a numerical model for determining the profile of the Cutter Tooth was developed.

RESEARCH METHODOLOGY

The Oilseed Flax gathering is associated with its ripeness and, with the condition of the ripening of the seminal part in the phases of early or early yellow ripeness; segmental-finger cutting devices are used. In this paper, particular attention is paid to the amount of stem cutting effort for three positions: compartment, middle and upper. At the same time, the initial relative humidity of the stems ranged from 13-15% for the stock and 21.8% of the stems in early ripeness. The cutting force of the stems was determined with the help of the developed laboratory stand. (see Fig. 1).

Fig. 1. The laboratory stand for researches

Thus, the technical means should predict the possibility both of cutting the Oilseed Flax stems and the pulling. The complexity of obtaining raw material for fiber from the Oilseed Flax stems occurs at the stage of its harvesting. The fiber is directly dependent on the natural and climatic conditions in a certain period, the conditions for obtaining the stock and the proper amount of technical means.

Cad-systems, in particular, "KOMPAS" and "AutoCad", were used for the development of a 3D volumetric model of grinding tools for Oilseed Flax and a profile of Cutter Tooth. Mathematical modeling of the process of plant papers transferring to the surface of the Cutter Tooth was based on the theory of differential equations of motion of a point with rough surfaces. A numerical experiment by means of the developed mathematical models was performed in the mathematical package MathCad. The solution of the differential equations was based on the numerical Runge-Kutta calculation method of the 4th order. To verify the results of theoretical studies, a laboratory plant (see Fig. 2) was used to obtain well-shredded stems.

a) b)

Fig. 2. General view of the laboratory plant for grinding Oilseed Flax (a) and the position of cutting knives in the body (b)

RESULTS

The problem of transforming the stem mass into the stock arises just at the flax harvesting stage with an Oilseed Flax combine harvester (see Fig.3), when a roll of stalks with dimensions in the cross section in the range of 1.0 × 0.5 m is formed in the field. From Fig. 3 shows that the stems in the rolls are chaotic. This makes it difficult to use the rotation operation while converting them into a stock. Also, the terms for harvesting Oilseed Flax depend on weather conditions and, as a result, there will be a different phase of ripeness of the crop. Therefore, the quality of the fiber will be different. The results of the determination of the complex quality index for fiber from Oilseed Flax grown in the conditions of the Western Polissya in the phase of early yellow ripe-ness (Fig. 3a) and the comparison with Flax fibers indicates the prospect of using Oilseed Flax fiber in the textile industry [3]. However, the harvesting of Oilseed Flax in the phase of full ripeness (see Fig. 3b) indicates a loss of quality of the stem mass and the quality of the fiber.

a) b)

Fig. 3. Rolls of Oilseed Flax made by a combine harvester at different phase of ripeness: a) early yellow ripeness; b) - ripeness

For effective destruction of the stem part of Oilseed Flax, a mechanical device with rotor drums has been proposed (see Fig. 4) [15…18]. It includes two main assemblies placed on the frame 1: shaper 2 of layer 3 takeoff reel 4, rolls 5 and 6 and rotor 7 with knives 8 with worksurface 3.

Experimental verification of the proposed types of knives proved the effectiveness of the destruction of Oilseed Flax stems, taking into account the phase of ripeness and further usage of the fibrous mass. To reduce the elastic properties of the stems at the stage of converting them into a stock, it is possible to use hammer-type knives. Then the awn is partially removed from the stems, and the height of the roll is halved, which contributes to the intensive penetration of moisture from both the field surface and the environment, ensuring the intensive development of pectin-destructive bacteria.

For high-quality operation of the device for grinding bast raw materials, it is important to ensure the working conditions of the mechanism. Thus, it is necessary in this way to select the e-dimensions of the Cutter Tooth and the kinematic parameters of the rotor, which will guaranteed the grinding of the stem in the cutting zone that. This zone is characterized by the trajectory by which the conventional stem moves, which is located on the working surface of the knife from the pickup, point A_1 of the material to the point A_2. The point A_2 is the extreme point where the stem breaks down (see Fig. 5). The provision of this condition is possible with the appropriate rotor tooth profile. Since in the cutting zone, the stem section has a diameter in the range of 1 ... 2 mm, the process of its movement can be described as the movement of a material paper M on a rough surface. We introduce a coordinate system YOX with a center at the top of the Cutter Tooth and suppose that the rotor is stopped and does not rotate, and the plant material moves along the Cutter Tooth surface and rotates around the axis O_1 at the same time. In this case, the material paper M will carry out the transport motion - rotational with angular velocity ω, and the relative motion - translational linear velocity V_r.

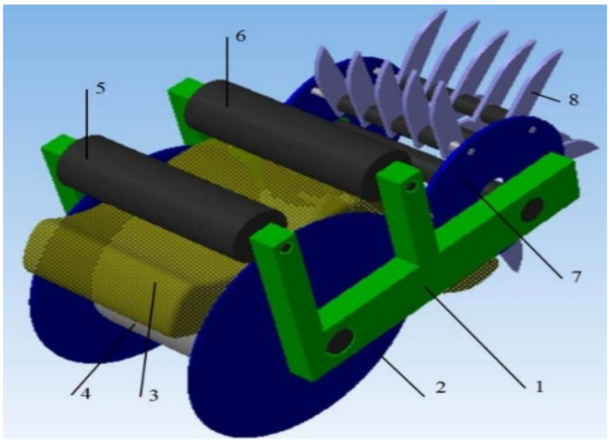


Fig. 4. The plant scheme of stem mass destruction

In addition, the following assumptions must be made to solve the problem:

- the material paper moves from point A_1 to point A_2 during the turn from position $\varphi = \pi/2$ to position $\varphi = 0$;
- the movement of a material paper M on the working surface of the Cutter Tooth occurs in proportion to the change in the angle φ of the rotation of the drum.

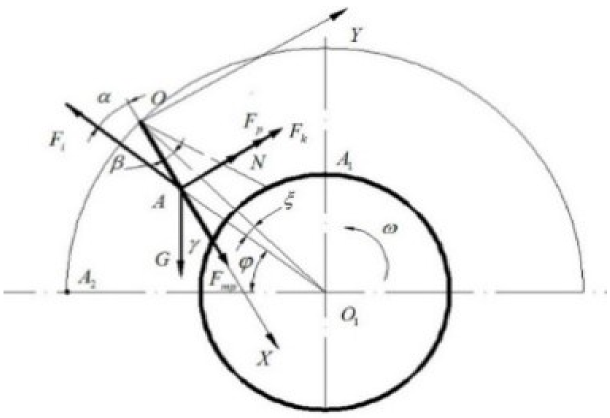


Fig. 5. Calculation scheme for determining the Cutter Tooth profile of the grinding device for bast raw materials

When the rotor tooth rotates, the stem paper M that entered it will rotate with it and move along its surface. At the same time such forces act on the material paper M: the paper gravity ($G = mg$), centrifugal inertia force ($F_i = mR\omega^2$), Coriolis force ($F_\kappa = 2m\omega V_r$), friction force ($F_{mp} = f_{mp} \cdot N$), cutting force F_p. To match the model, only its normal component is taken into account, where R - the rotor radius, ω the angular velocity of the rotor rotation, m - the mass of the material paper, f_{mp} - the coefficient of friction of the stem sliding along the metal.

Let us compose a system of equations for the sum of the projection of forces acting on a paper in the direction perpendicular to the Cutter Tooth surface and the projection of forces on the axis OX and, solving them, we obtain the differential equation of paper motion by the Cutter Tooth surface:

$$\ddot{x} = f_{mp}\left[R\omega^2\sin\alpha - \frac{F_p}{m} + 2\omega\dot{x} + g\sin\gamma\right] - R\omega^2\cos\alpha + g\cos\gamma \qquad (1)$$

The Cutter Tooth profile of the drum will be determined by changing the angle β at the height of the Cutter Tooth. The angle β is the angle between the line passing through the top of the Cutter Tooth p. A. And the center of rotation of the drum p. O_1 and perpendicular to the normal reaction of the Cutter Tooth surface. Determination of angles is carried out in accordance with Fig. 4, and substituting into formula 1, we obtain the final level of motion of the p. A

$$\ddot{x} = f_{mp}\left[R\omega^2\sin\left(\arcsin\frac{x\cdot\sin|\beta|}{\sqrt{x^2+(R+H)^2-2x(R+H)\cos\beta}}+\beta\right)-\frac{F_p}{m}+2\omega\dot{x}+g\sin\left(\frac{\pi}{2}-\varphi-\beta\right)\right]-$$
$$-R\omega^2\cos\left(\arcsin\frac{x\cdot\sin|\beta|}{\sqrt{x^2+(R+H)^2-2x(R+H)\cos\beta}}+\beta\right)+g\cos\left(\frac{\pi}{2}-\varphi-\beta\right) \qquad (2)$$

The optimization problem as a design parameter is chosen the angle of the Cutter Tooth profile β, the target function is the path taken by the material paper M during its movement and is described by equation (3), and the constraints are the geometric and kinematic parameters of the mechanism (R, H, ω). That is, the optimization problem is formalized as following:

$$\left.\begin{array}{l}\ddot{x}_i(\tau)\rightarrow\max\\ 0\le\varphi\le\dfrac{\pi}{2}\end{array}\right\} \qquad (3)$$

Finding a solution to system (9) at each moment of time τ_i means setting such a profile angle β_i value at which $\ddot{\ }$ x. That is, the material paper M will move from the base of the Cutter Tooth to its top in the maximum possible way. This makes it possible to perform the cutting conditions of plant materials as accurately as possible. A numerical experiment was performed by using the mathematical package MathCad. Since the analytical solution of the second-order differential equation (4) causes difficulties, we used numerical isolation schemes, in particular, by using the Runge-Kutta method is a fixed step. While calculating, the following numerical values of the parameters were used: Rotor radius $R = 0.3$ m; Cutter Tooth height $H = 0.1$ m; angular velocity of rotation of the rotor $\omega = 5\ldots$ s[-1]; coefficient of sliding friction $f_{mp} = 0.2$; normal component of the cutting force $F_p = 40$ H; mass of stem $m = 1\ldots$ g.

The result of the calculations was obtained in the form of graphs (see Fig. 6).

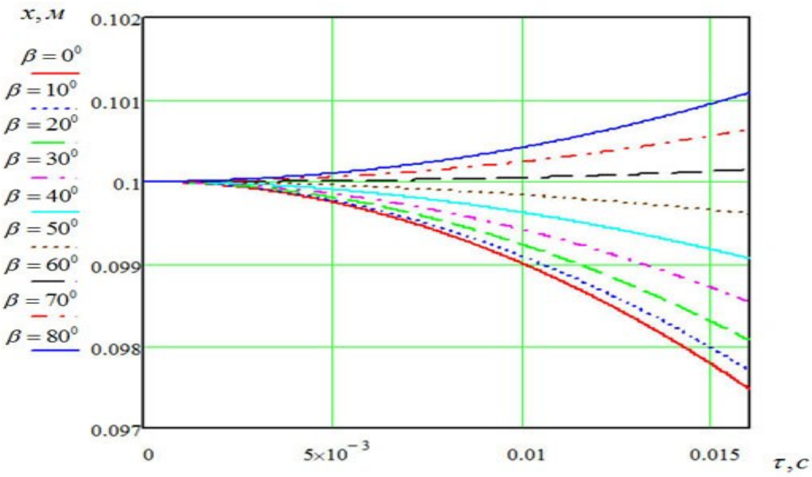
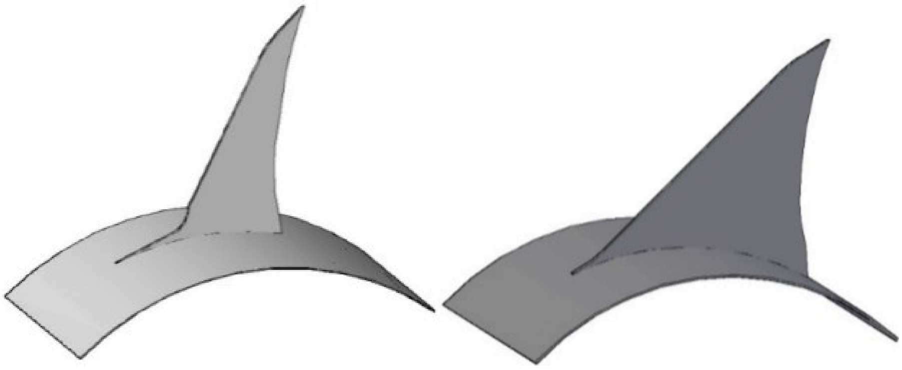


Fig. 6. The change of coordinate x point M with the time

The analysis of the results of the proposed mathematical model of the Cutter Tooth profile showed that the angular velocity of the Rotor wrapping has a significant effect on the profile curvature. At speeds $\omega < 5\,s^{-1}$, a "sticking" of a material paper is observed at the base of the Cutter Tooth and its movement along the cutting surface is not observed. Based on the calculations, the Cutter Tooth grinding mechanism is S-shaped (see Fig. 7). The greatest curvature of the profile is observed at the base and at the top.

Only minor portions of the Cutter Tooth profile have significant curvature. To improve the technology of Cutter Tooth making, use of teeth with a linear profile can be tolerated. It is only necessary to choose the optimal angle of inclination of the Cutter Tooth β. The graphic result of the calculation of the movement point M of the surface of the whole Cutter Tooth is shown in Fig.8.



a) b)

Fig. 7. The calculated profile of the Cutter Tooth: a) $\omega = 20\,s^{-1}$, b) $\omega = 40\,s^{-1}$

According to the calculations, the rational angle of inclination of the Cutter Tooth β is 50°. At this angle, the working surface of the Cutter Tooth should be done with a straight line and not closer to the top at a distance of 40 mm, the working surface should be rounded.

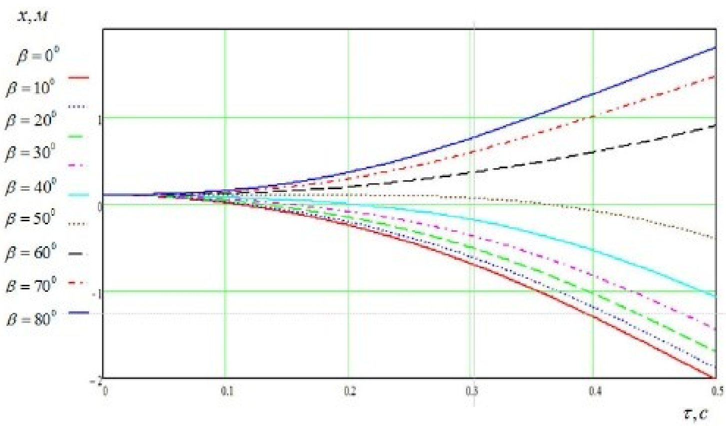


Fig. 8. The choice of the angular of the linear Cutter Tooth profile

Experimental studies have confirmed theoretical calculations to establish the cutting angle of oil flax stems, which is used both in the segment-finger cutting devices and in installations for breaking the stem mass during its gathering and singling out of short unoriented fiber. The analysis of the experimental data obtained indicates that the use of a segmental finger cutting device for the gathering of oilseed flax has an important cutting angle and it should approach 60° in the communal zone. Experiments show that in the full ripeness phase the cutting angle does not affect the applied force. At the same time, the resistance of the cutting of stems in the communal part fluctuates within the limits of 17.0 N, the middle part is 12.5 N, and in the upper part it is 7.7 N. A slight force indicates a considerable jumble of the stem. In this case it is necessary to use a flax puller for the gathering of Oilseed Flax

Thus, the principle of grinding the stem mass of oil flax can be laid in the design of a universal combine. Then it is enough just to destroy the surface part of the stems in the early ripeness phase and, as a result, to obtain a fiber suitable for usage in the textile industry. But at the same time for highlighting the fiber, it is necessary to grind the straw pulp. In the case of the gathering of Oilseed Flax in the phase of full ripeness, when the fiber loses its valuable textile properties, straw can be formed into fuel materials. The papers of awn selected by the proposed device (see Fig. 9) with a length of 3-5 mm can be directed to the production of fuel briquettes, and the fiber of an average length of 30-50 mm for additional treatment with subsequent use in various areas.

a) b)

Fig. 9. The components of the stem part of the Oilseed Flax after grinding by the device: a) awn; b) fiber

CONCLUSIONS

For each natural and climatic condition in crop rotation there must be crops which requires the use of a minimum amount of technology. Oilseed Flax is referred to industrial crops, but the technology for producing products from it is similar to the plants of the grain group. According to the scientific approach, Oilseed Flax is considered to be a culture of waste-free production, but a high stem, which can reach one meter has become an obstacle in the wide distribution of oil flax on the territory of Western Polissya. Therefore, the results presented in the paper indicate the prospect of applying the combined approach when using the stalk of flax oil. The technologies for the production of oil flax in the conditions of Western Polissya are imperfect and need to be modernized with harvesting operations in order to use the full potential of the plant. The main problem that has not been solved to date is the utilization of the stem part of the crop. For utilization of NOT crop seed residues, a method of modeling the means for grinding the stem part of oil flax has been proposed. Further processing of such raw materials is possible through the manufacture of fuel materials.

In accordance with the weather conditions of the current season, it is possible to obtain high-quality non-oriented fiber or cylindrical fuel materials from the stems. For both cases, the destruction of the stems operation is required. Theoretical and experimental studies have been carried out that make it possible to obtain and apply mathematical models in the calculation and design of machines and units required for the proposed technology of cultivating Oilseed Flax.

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