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RESEARCH ARTICLE

Analysis of the Model of the Grain Separation Process Through a Permeable Threshing Medium, Taking Into Account the Geometric Parameters of the Drumming

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ABSTRACT

The paper presents an analytical consideration of the issue of grain separation through a permeable threshing medium, through the lattice structures of the concave, taking into account the geometric parameters. A model of the elementary probability of sifting grain through the concave is studied as a convenient characteristic of the separating capacity of the lattice surface, associated with the parameters of the working elements, the role of which increases due to the significant permeability of the threshing medium. A method for the probability of grain separation through a permeable lattice during threshing is considered. A diagram of grain separation from the threshing space, a diagram for determining the dependence of the attack angle on the concave length, a diagram for determining the angle of displacement of the grain flow are compiled. Formulas are obtained for the geometric probability of sifting; the angle of attack of an elementary layer of stalks; the pitch of the lattice of stalks at any point of the threshing space; a formula for determining the angle of displacement of the grain flow. The main directions of search here can be considered to be increasing the degree of rarefaction of the flow of plant mass entering the threshing space due to its preliminary dragging or increasing the permeability of the threshed product by preliminary deformation.

INTRODUCTION

According to established tradition, it is considered that the main theoretical task in the study of grain extraction by a threshing machine is to obtain the separation equation, which most often provides a relationship between losses y and feed q and the length of the drumming l

$$y = f(q, l, \mu),$$

where μ is the separation coefficient.

Usually, an integral part of the coefficient μ is the probability α of sifting grain from the threshing space in one cycle, per unit of time, in one attempt.

The elementary probability of sieving is a convenient characteristic of the separating ability of a grated surface, for example, a hammering grate, and, being related to the parameters of the working elements, the role of which increases due to the significant permeability of the threshed medium, it can serve as a measure of compliance with the geometry of the surface (especially at the entrance of the threshing space) the best separation condition. At the inlet, where the grain flow is most concentrated, the parameters of the working elements of the drumming can be optimized using the formula for the probability of sieving from the angle of maximum separation in the presence of restrictions.

In addition to the possibilities of optimizing the parameters and operating mode of the threshing machine, the separation equation, as a mathematical model, is conveniently verifiable using easily obtained experimental data of zonal grain separation.

The basis for studying separation, as well as any process studied at the initial stage, is the construction of a clearly defined, even if not completely rigorous, model of objects of the separation complex [1,2].

The permeability of the threshed mass depends on its condition (moisture, spinous, weed infestation, etc.), the feed rate, the operating mode of the threshing machine, and its adjustments. Under some average optimal threshing conditions, the whole variety of influencing factors can be reduced, for example, to feed and clearances. Then the permeability will depend on the number of stems and their location in the threshing space, and the number of stems is determined by the feed, through it and the flow rate, which reaches 21 m / s [3], and their position is determined by the gaps at the inlet and outlet.

MATERIALS AND METHODS

The number of stems per unit width of the thresher, depending on the feed rate, is set in [4]. It identifies two characteristic areas of the drumming: the entrance area (approximately 100 mm) and the rest of the latticed surface. When feeding more than 5 kg /s, the stems at the entrance, as it turned out as a result of research, move in a continuous stream with a thickness of 3 - 6 mm (in one or two stems). In the middle and at the end of the threshing space, the stems move with gaps in the projection onto the surface of the drumming.

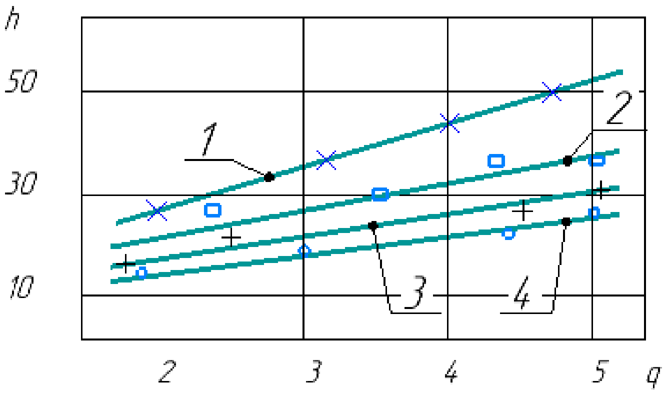

Figure 1: Dependence of the degree of rarefaction of the stem flow depending on the supply of plant mass

Figure 1 shows a graph of the dependence of the number of stems per 1 cm of the length of the bar on the feed on various parts of the drumming surface. It can be assumed that with an increase in feed above 5 kg/s, the number of layers in the threshing space will increase proportionally.

If we proceed from the uniform filling of the threshing space with the threshing mass, then with a two-row placement of 50 stems, the average distance between the stems in one row will be 9.2 mm with a bar length of 23 cm [5]. Therefore, with an average stem diameter of 3 mm, the gap between the stems when viewed from above, as in video shooting [6], will be 0.1 mm, that is, the flow of stems will appear continuous.

When constructing the separation scheme, it was assumed that the stems in the threshing space are evenly spaced at any feed in 1, 2, etc. layers, and their direction coincides with the direction of the hammering rods. Uniformity implies the same gaps between the stems in any direction.

To a first approximation, the stems are considered as absolutely elastic rods of some average diameter. The grain model is a ball with a radius less than half the average length of a 2d grain. The radius value is determined from the condition of equality of the probabilities of reflection of the grain and the model from an obstacle (rod, bar) into a strip of the screen with a width of d [7].

Two qualitatively different separation stages were considered, but they share the common property that the grain flow attacks the spatial lattice at high speeds in both cases. The outcome of the attack was determined by the probability of sifting.

The primary stream has been allocated. It is formed at the first blows of the whips on the ears at point A (Fig. 5.2) and forms a spectrum of trajectories inside the angle β*=π/2. This premise is confirmed experimentally [8]. For the rest of the threshing space, the grains moved tangentially to the circumference of the whips, attacking the hammering grid at sharp angles β.

The formation of a spectrum of trajectories at point A is quite obvious if we proceed from the concept of free collision and randomness of the bonds holding the grains in the ear. Inside the threshing space, the blows of the whips on the unfilled ears or on the free grains reflected by the hammering are inflicted in conditions of capture by the reefs [9] and interference from the stems, limiting the freedom of movement of the grains accelerated by impact in the radial direction. Such may be the arguments in favor of the assumption made above about the tangential movement of grains in the "rest" of the threshing space.

The fate of the grains trapped by the layer, especially at the entrance, can be twofold. They will either be carried outside the drumming area along with the flow of plant matter, or they will reach the lattice surface under the action of centrifugal forces. In the second case, the angle of attack will obviously differ little from the angle β2 in Figure 2.

Grains can also be removed from the threshing space as a result of sequential reflection from the surfaces of the drum and drumming [10]. Thus, losses "off the batter" form two streams: free grains trapped by the layer (the phenomenon of transfer according to E.I. Lipkovich) and grains reflected by the impact of the scourges. We assume that under the average optimal threshing conditions (relatively complete threshing at the inlet, homogeneous vegetable mass, uniform feeding, etc.), the main share of losses is made up of "reflected" grains. In conditions of high humidity, clogging, and confusion of the threshed mass, which contribute to the formation of significant portions and uneven feeding, the first type of loss prevails. The pattern of formation of the latter was studied in [11].

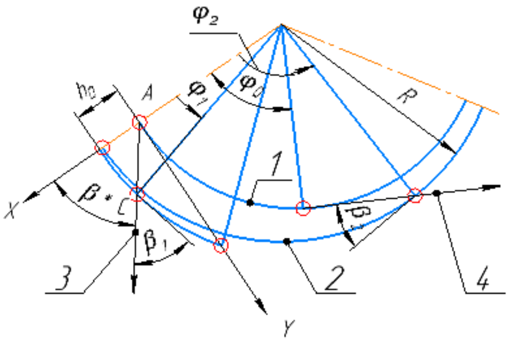

Figure 2: Schematic diagram of grain separation: 1 is the circle of the scourge, 2 is the circle of the rumming, 3 is the trajectory of the primary flow, 4 is the trajectory of the secondary flow

It is known that the probability of grain separation during threshing is determined through the product of the probabilities of successive passage of grains through a 1,2..n-layer straw grating, slatted and bar grating.

Due to the change in the parameters of the gratings along the length of the sub-drum, the partial and therefore the total probability of sieving will also change. The concept of primary secondary flows and their analytical description are given in [12].

When analyzing the separation process, it is assumed that the probability of sieving through a grate is equivalent to the probability of grain passing through a separate cell of the grated surface outlined by adjacent bars and slats. With this approach, the probability of screening is equal to the live section of the cell, that is, the ratio of the lumen area to the total area of the cell. With some clarifications, this definition of probability is also found in the works of other authors.

RESULTS OF THE RESEARCH

It can be assumed with a high degree of confidence that the probability determination method considered above has been transferred to the case of "rotary" separation from the theory of separating grain from a coarse pile from a coarse pile on a keyboard straw [13]. However, the legality of such a transfer is hardly justified. In fact, during the "keyboard" separation, the grain trajectories are mostly normal to the lattice surface. In addition, the grain size is small compared to the cell size. The impact rates of the grains with the lattice surface are also low, which minimizes the effect of reflection of the grains back into the layer with any reflection trajectory.

Under these conditions, taking into account the representation of grain as a material point (Fig. 3a), the probability of sieving can be determined using the ratio

$$\alpha = \frac{l}{L}$$

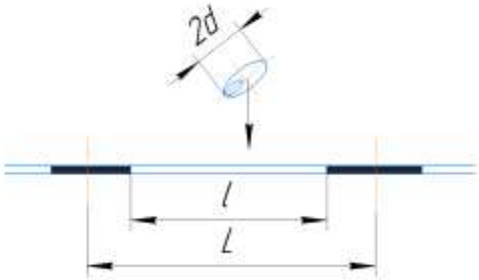

Figure 3a: Sifting grain through a grid unit cell at high angles of attack

A different pattern will be observed in the threshing space, where the vast majority of grains attack the surface of the drumming at low angles β (Fig. 3b) and at high speeds. In this case, the largest 2d grain size becomes commensurate (and may be smaller) with the value $l_1 = l \sin\beta$.

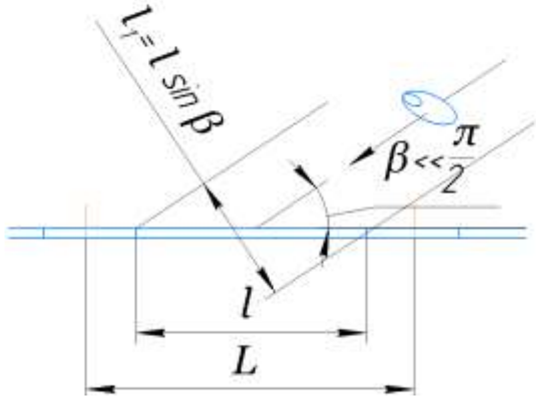

Figure 3b: Grain sifting through a grid unit cell at low angles of attack

On the other hand, at a low angle β, the nature of the grain's collision with the physical boundaries of the cell increases, because it is quite obvious that simply "filling in" the boundary does not necessarily mean not sieving; reflecting off the contour, the grain can penetrate into the cell. High reflection rates should also play an essential role. They will clearly delineate the sifting and reflection trajectories to the threshing drum, giving the latter a rectilinear character in the cell area.

Considering the hammering grid as spatial (different levels of arrangement of rods and working faces of slats), the passage of grains through the hammering was presented as a sequential overcoming of both lattice surfaces. Then the probability α of sifting through the drumming is

$$\alpha = \alpha_{\text{ПЛ}}\alpha_{\text{ПР}},$$

where $\alpha_{\text{ПЛ}}$ - the probability of separation through a slatted grate,

$\alpha_{\text{ПР}}$ -

On the other hand, the probability of grain sifting through the unit cell of the separating surface of the sub-drum (and in general the curved lattice surface of the rotary separator) can be defined [14] as the difference between unity and the product of the probability of a grain collision with the working element of the cell and the probability of grain reflection to the drum upon collision. The convenience of this approach can be justified both from a mathematical standpoint and from the point of view of establishing links between reflection probabilities and technological processes.

In the threshing space, the grains sequentially overcome the lattice layers of longitudinally oriented stems. Figure 4 shows the normal section of an elementary cell of such a lattice attacked in the j direction by a homogeneous flow consisting of grains in the form of balls of reduced radius r_2. The cell is formed by adjacent stems of radiusr_1, separated by a space t_s. It was assumed that when the grain is reflected horizontally from the stem, separation does not occur. The act of separation will not happen, and even more so with coal $\varphi > {}^{\pi}/_{4}$. Then, the location of the trajectory of the "fall" inside the segment a_c guarantees the passage of grain through the cell. Therefore, the geometric probability of sieving can be found as the ratio

$$\alpha_{\text{PM}} = \frac{a_c}{t_c}$$

by $\psi = {}^{\pi}/_{4}$

$$a_c = t_c - 1.41(r_1 + r_2).$$

Then

$$\alpha_{\text{PM}} = 1 - 1{,}41\frac{r_1+r_2}{t_c} \qquad (1)$$

According to the accepted separation scheme, the vast majority of grains attack the lattice of stalks in the angle range from some small β to $\beta = {}^{\pi}/_{2}$(Figure 2). In this case, the probability is α_{PM} is a function of the angle of attack β. Let's find the dependency $\alpha_{\text{PM}}(\beta)$.

The result of the intersection of the trajectory plane with the stem surface at an angle not equal to ${}^{\pi}/_{2}$ It can be considered as an ellipse with parameters depending on the angle β. The section of the ellipse arc of the greatest curvature, which determines the conditions for grain reflection, can be approximated with a sufficient degree of accuracy by a circle of radius

$$r_{\text{PM}} = \frac{b^2}{a^2}\sqrt{2a^2 - b^2},$$

where a, b- the major and minor semi-axes of the ellipse, respectively. The latter ratio was obtained in [15]. Expressing the parameter a in terms of r_1 and β, we find it definitively

$$r_{PM} = r_1 \sin\beta \sqrt{1 + \cos^2\beta}. \qquad (2)$$

Thus, when $0 \leq \beta \leq {}^{\pi}/_{2}$ A grid of elliptical elements can be replaced by an equivalent bar grid with a bar radius determined depending on the angle β according to formula (2).

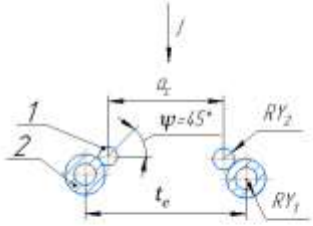

Figure 4: Scheme for determining the probability of sifting through a lattice of stalks: 1 is a grain in the form of a ball of reduced radius, 2 is a stalk

Taking into account expression (2), relation (1) takes the form

$$\alpha_{\text{PM}} = 1 - 1{,}41\frac{Y_1 \sin\beta\sqrt{1+\cos^2\beta}}{t_c} \qquad (3)$$

DISCUSSION

A scheme for determining the dependence of the angle of attack β on the length of the drum (girth angle) for the primary grain flow is shown in Figure 5. At φ=0, there is a radial flow direction. The deviation of the trajectory from the actual direction is set by the angle β^*. Point A is still the starting point of the trajectories of the spectrum. Let's find the corners β^* and β in relation to φ .

It was assumed that at a small angle of girth $h = h_0 = const$. The equation of an arbitrary AC trajectory has the form

$$y = \text{tg}\,\beta^* x \qquad (4)$$

In this case, the coordinates of point C are:

$$X_c = R\cos\varphi - (R - h_0),$$

$$Y_C = R\sin\varphi$$

Taking into account the last two relations from equation (4), we obtain

$$\beta^* = \text{arctg}\frac{\sin\varphi}{\cos\varphi(1-\frac{h_0}{R})}$$

On the other hand, we have an obvious equality

$$\beta = \frac{\pi}{2} - \beta^* - \varphi.$$

Then the angle of attack of the elementary layer of stems can be found from the expression

$$\beta = \frac{\pi}{2} + \varphi - \text{arctg}\frac{\sin\varphi}{\cos\varphi - (1-\frac{h_0}{R})} \qquad (5)$$

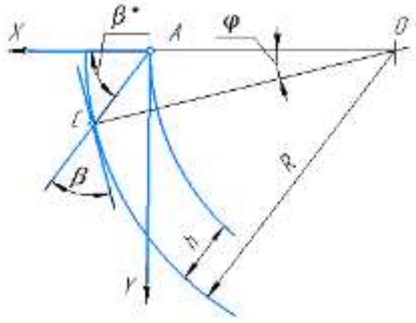

Figure 5: The scheme for determining the relationship $\boldsymbol{\beta = \beta(\varphi)}$

It follows from the latter relation that when $\beta^* = \frac{\pi}{2}$

$$\beta = \varphi$$

This equality is valid for any trajectory tangent to the circle of the whips, with proper choice of the coordinate axes and the gap between the drum and the drumming.

For $\beta = \varphi$ from (5) it follows that

$$\operatorname{arctg} \frac{\sin\varphi}{\cos\varphi - (1 - \frac{h_0}{R})} = \frac{\pi}{2},$$

and the latter is possible if

$$\cos\varphi - (1 - \frac{h_0}{R}) = 0,$$

from where we have

$$^{\varphi}\!\big/_{\beta^* = \frac{\pi}{2}} = \varphi^* = \arccos\ (1 - \frac{h_0}{R}) \qquad (6)$$

Over a considerable length of the battering, the change in the angle β depending on the narrowing of the gaps will be significant (unlike the length of the zone attacked by the primary flow), and then for any point, excluding point A, on the circle of the whips in formula (6) at $h_0 = h$ it is necessary to take into account the dependence of h and φ, we find

$$h = h_0 - \frac{h_0 - h_n}{\varphi_n}\varphi \qquad (7)$$

where h_0 - outlet clearance,

h_n - outlet clearance,

φ_n - the angle of circumference of the drum by tapping.

Taking into account (7) for φ > φ* the angle of attack value is determined by the ratio

$$\beta^* = arc\cos\ [1 - \frac{1}{R}(h_0 - \frac{h_0 - h_n}{\varphi_n}\varphi \qquad (8)$$

By analogy with the previous one, taking the linear dependence of the step of the lattice of stems on the angle of girth, we obtain the following formula for determining the step at any point of the threshing space

$$t_c = t_n - \frac{t_n - t_0}{\varphi_n}(\varphi_n - \varphi), \qquad (9)$$

where t_0 - initial step value,

t_n - the final step value (at the exit of the threshing space).

The flow of stems is most dense at the entrance of the drum, that is, where the flow of free grains is most intense. These two factors, which fundamentally affect separation, require the most careful consideration. Because the grains attack the stems at angles mostly different from $^{\pi}/_{2}$, the question arises about the displacement as a result of the scattering of the grain flow, each trajectory of which will reach the surface of the drumming on the coal $\varphi_{\text{см}} > \varphi$.

Consider the extreme trajectory AE of the primary flow (Fig. 6). If the number of elementary layers at the input is i, then the intersection of this trajectory with the first layer will occur on an arc of radius $R - \Delta_h$, where Δ_h- the distance between the layers. At point E, the grain, reflected from the stem, can choose any continuation of movement inside the corner 2β. On average, it was assumed that the grain would move in the direction of ET, and thus came to the problem of determining the angle φ_2 for a new trajectory, but according to the old scheme. Now the role of point A is played by point E, and the trajectory is ET ⊥ EO; the point equivalent to point E is located on an arc of radius

$$R-(i-1)\triangle h \text{ etc}$$

From triangle AOE we have

$$\varphi_0 = arccos\frac{R-h}{R-i\Delta_h} \qquad (10)$$

By analogy, we find:

$$\varphi_1 = arccos\frac{R-i\Delta_h}{R-(i-1)\Delta_h} \ ,$$

$$\varphi_2 = arccos\frac{R-(i-1)\Delta_h}{R-(i-2)\Delta_h} \ ,$$

$$\varphi_3 = arccos\frac{R-(i-2)\Delta_h}{R-(i-3)\Delta_h} \ ,$$

…………………………

$$\varphi_i = arccos\frac{R-\Delta_h}{R} \ .$$

The general form of the formula for determining the angle of displacement at any level of the stem layer has the form

$$\varphi_{j+1} = \arccos\frac{R-(i-j)\Delta_h}{R-[i-(j+1)]\Delta_h}, \ \ j = 0,1,2,\dots,i-1$$

Then the total angle of displacement of the AE trajectory with the number of layers will be

$$\varphi_{\text{см}_i} = \sum_{j=0}^{i-1}\varphi_{j+1} \ , j = 0,1,2,\dots,i-1$$

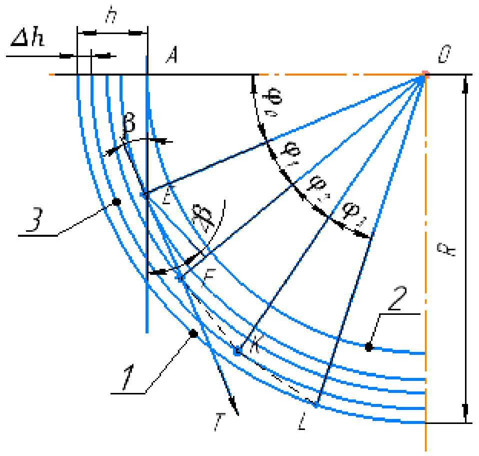

Figure 6: The scheme for determining the angle of displacement $\varphi_{\text{см}}$ grain flow

But with little Δh compared to R angles $\varphi_1, \varphi_2, \dots \varphi_i$ they will differ insignificantly from each other, as a result of which it can be assumed that

$$\varphi_{c\text{м}_i} = i \arccos \frac{R-\Delta_h}{R} \qquad (11)$$

Obviously, with the accepted scheme, the magnitude of the elementary displacement (and therefore the total) does not depend on the type of trajectory originating from point A within the angle β^*.

CONCLUSION

Based on an analytical consideration of the issue of grain separation through a permeable threshing medium filling the threshing space, as well as through the lattice structures of the drumming, taking into account the geometric parameters of the working elements of the latter, we can conclude the following. A basic separation scheme has been developed that takes into account the properties of the plant mass as a permeable medium. The scheme has significant generality and reflects the behavior of high-speed grain flows in threshing machines, which differ in a wide range of design parameters.

In addition, it can be used in modeling any processes associated with impact at the inlet of the device, as well as with the subsequent transportation of the processed material in space with the possibility of cyclic interaction with its variously perforated work surfaces, producing separation of components on a probabilistic basis.

This approach can be extended to the operation of threshing machines of other designs, in particular, a pin type, as well as to the functioning of various beater devices (receiving and chipping beaters, beater-concentrators of the pile in the cleaning system, a swing beater of a two-drum threshing machine) and generally any rotary working bodies that carry out the processes of threshing and separation of various crops., as well as other similar processes, such as crushing. The developed concept of screening probabilities has withstood experimental verification, and the corresponding theoretical model of the elementary act of separation has shown sufficient sensitivity to changes in design parameters.

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